Chapter 1. Climate Change: New Dimensions in Disaster Risk, Exposure, Vulnerability, and Resilience

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Executive Summary

This report addresses three major challenges associated with anthropogenic climate change and the management of disaster risk.

The first challenge is identifying and assessing the concepts, experiences, methods, strategies, and instruments used in disaster risk management that are likely to be most relevant and useful for climate change adaptation.

The second is identifying and assessing the modifications to current disaster risk management practice that climate change and climate change adaptation may require, and facilitating the required transition in concept, method, and practice.

The third challenge lies in consolidating the revisions in disaster risk management into climate change adaptation theory and practice.

This chapter lays out the conceptual premises, key notions, definitions and assumptions with which the climate change adaptation and disaster risk management communities, and sub-communities within them, operate. It seeks a more holistic, integrated, interdisciplinary approach than currently exists in order to bridge existing gaps.

A central concern is that climate change has introduced substantial non-stationarity into risk management decisions. Non-stationarity is the realization that past experiences may no longer be a reliable predictor of the future character and frequency of events; it applies both to hazards and to the response of human systems to same. As climate change is expected to change the frequency, magnitude, and other characteristics of extreme events, some of which are associated with extreme impacts, risk management strategies must accomodate a shifting distribution of the latter.

Extreme events do not bear a one-to-one relationship with extreme impacts. Some extreme events involving *extreme direct and indirect social and economic impacts* can be characterized as contributing in an important way to the occurrence of “disaster”. Disasters occur when extreme impacts cause a severe disruption of the normal, routine functioning of the affected society. However, depending on the context, physical extremes may or may not bring along extreme impacts and disasters.

Disaster may also arise from a concatenation of physical, ecological and social reactions to lesser physical events, or to moderate events superimposed onto a gradual trend. Disasters are predicated on the existence of vulnerability, which can be exacerbated by pre-existing social processes and events, such as financial crises, trade policies, wars, disease outbreaks, etc.

Climate change and its attendant additional risks and opportunities will inevitably be understood and responded to at multiple scales, from the individual household to the national and international level, and will likewise occur in the context of other economic, political, technological, and cultural shifts.

Disaster risk management and climate change adaptation policy, strategies and instruments will only be successful if understanding and intervention are based on multi-scale principles and if the complex interactions between phenomena and actions at local, sub-national, national and international scales are appreciated and anticipated.

Probabilistic risk analysis offers a powerful and elegant framework for addressing non-stationarity, but there exist numerous challenges to implementing it for disaster risk management and climate change adaptation. Many communities lack the training and data to implement this framework in practice. But even in the most favorable real-world situations, fundamental problems of estimating probabilities of both events and consequences, as well as problems of risk communication, markedly complicate implementation of a risk management framework.

In particular, the judgment and decision-making literature suggests various cognitive barriers that make it more difficult for individuals and organizations to properly assimilate and respond to information about low probability events. Effective risk communication requires a process of exchanging and integrating knowledge and information about climate-related risks among all stakeholder groups. Motivational factors also introduce differences in perceptions and reactions as the result of variations in values and beliefs.

Moreover, disaster risks do not exist in isolation, and ultimately cannot be separated from the ongoing, chronic or persistent social risk factors that typify everyday life for many individuals. Climate change introduces further complexity as a result of both shifting averages and shifting extremes.

Currently, most of the human losses (in absolute terms) and economic losses (in relative terms) due to extreme events are borne by developing countries. Climate change is expected to amplify this trend. Improving the management of extreme events and extreme impacts is often complicated by the lack of reliable and timely information on disaster risk, a lack felt most acutely in the developing world. Poverty also increases enormously the impacts of adverse exposures to hazards and extreme events, and significantly complicates risk prevention and reduction efforts.

The role of development is a key factor in climate change adaptation. Related to this line of inquiry is the contentious relationship between *coping* and *adapting* In the disaster risk management literature, the term coping appears to have derived from an interest in understanding *ex post* responses to disasters particularly amongst poorer populations, where few practical alternatives to achieve risk reduction or to bolster bottom-up approaches are readily available. As a result, coping has increasingly been comingled with adaptation, as disaster risk management practice has become more development oriented. Nevertheless, a tension remains because adaptation tends to emphasize *ex ante* approaches to risk management.

The synergistic relations between disaster risk, poverty, mismanagement of natural resources, lack of land use planning, and severe problems of governance in many countries and the challenge of climate change adaptation requires that intervention schemes assume a novel level of integration and coordination. The sectorialised views and actions of many government and international agencies are not currently well positioned for such an approach. Iintegrating disaster risk management and climate change adaptation thus presents an important opportunity for advanced learning processes that open up the possibility of significant revisions to both established theory and practice.

1.1. Introduction

1.1.1. Purpose and Scope

Anthropogenic climate change is projected to continue during this century and beyond. This conclusion is robust under a wide range of scenarios for future greenhouse gas emissions, including some that anticipate emissions mitigation (IPCC, 2007). This change is very likely to be associated with an increase in disaster risk and the need for increased and improved disaster risk management and development planning processes.

Climate change refers to a long-term trend in the norms or averages of the characteristics of climate affecting particular geographical areas and the globe as a whole. Disaster risk refers to the potential future loss and damage associated with the impact of various types of physical events; disaster risk management refers to processes that anticipate or/and reduce disaster risk, respond to disasters, and manage recovery. Climate change adaptation refers to sustainable adjustments in society and ecosystems which moderate harm or exploit beneficial opportunities in response to existing or future predicted climate change.

This report addresses three major challenges associated with anthropogenic climate change and the management of disaster risk.

1) Assessing the relevance and utility for climate change adaptation, of the concepts, experiences, methods, strategies and instruments employed in the management of climate-related disaster risk under prior conditions of stationary or stable climate
2) Addressing the new challenges and requirements that climate change and climate change adaptation bring to the disaster risk management field and the modifications and transitions this requires in concept, method, and practice
3) Assessing the implications of such revisions in disaster risk management for climate change adaptation.

This first section of the current chapter attempts to lay out the conceptual and thematic basics of the present report. Later sections will delve deeper into various essential element in defining the problematic, whilst future chapters will carry these forward in more detailed and specific ways. Among the existing or projected consequences of climate change are alterations in the frequency, intensity, geographic scale and location of “climate or weather events” and associated hydrologic and oceanographic phenomena, characteristics that are projected to deviate from the historical averages associated with a “stationary” or stable climate. Amongst these one can identify a category referred to as “extreme physical events” (abbreviated here as “extreme events”, see Chapter 3). Extreme events have been a facet of normal climate variability under stable climate conditions but their characteristics are expected to undergo modifications with future climate change such as to increase their potential for contributing to damage and loss in society and increased physical impacts on natural ecosystems (IPCC, 2007).

Some extreme events involving *extreme direct and indirect social and economic impacts* can be characterized as contributing in an important way to the occurrence of “disaster”. Disasters may essentially be defined as a severe disruption of the normal, routine functioning of the affected society.

Where such physical extremes do not impinge on societies that are exposed to their effects or where such societies show adequate levels of social, physical or economic resistance and resiliance, extreme events will not be associated with disaster. In constrast, disasters may result from physical phenomena that are not extreme but which nevertheless trigger negative social outcomes due to prevailing social and structural conditions (see Section 1.2 and Chapter 2 for a discussion of so-called “vulnerability” and “exposure”).

Developing and implementing means to respond reactively to these phenomena and the risk they signify has been the objective of what has been known as “disaster” or “emergency” management for many years. More recently and comprehensively, the term “disaster risk management” has emerged as emphasis has turned from “disaster” to “disaster risk” as a central concept. Disaster risk management includes greater efforts to build resistance against the potential impacts of extreme events at many scales, from household and community to the nation and region (see Section 1.3 for details of this transition).

Learning from earlier experience is a critical feature of disaster risk management. However, in contrast with previous experience, not only are the characteristics of extreme events changing, but they occur in a context typified by gradual changes in the mean state of the climate and the presence of other related phenomena such as sea level rise and shifting species ranges. Small changes in the mean state may be associated with large changes in climate extremes. Under such circumstances, disaster risk patterns will be modified and new patterns will emerge affecting in differential and differentiated ways all communities, regions, zones and nation states.

A deeper understanding and more certain projection of these ongoing changes and of the relations between different types and levels of disaster- triggering events and the impacts associated with them is necessary for effective disaster risk management and climate change adaptation. Experience with recent changes in characteristics of extreme events and impacts already provides a limited basis for improving disaster risk management. However, a continuously changing climate increases the complexity of learning and the application of lessons to disaster risk management.

The changing characteristics of extremes will result in greater uncertainty as to their intensity and distribution in space and time. They may also modify the path of development processes that in turn will change or modify existing vulnerability patterns (Patt et al 2010) and risk scenarios. New challenges, related to both changing mean climate and climate and weather extremes, resulting in new, unpredictable, and more complex risk scenarios, will very likely arise and new patterns of geographical risk exposure will very likely appear. These may involve changes in the combinations of the varied types of potentially damaging physical events any given society may face. The emergence of new physical threats may affect areas with no previous experience of these, whilst other areas may experience a decrease in historical risk factors.

1.1.2. Climate Change Adaptation and the Role of Disaster Risk Management

A principle goal of the present report relates to bridging the gap between the disaster risk management and climate change communities as regards conceptions, objectives and approaches to managing risk, including development of a concerted multi- and interdisciplinary approach useful to both. This inevitably requires framing the challenges faced by disaster risk management in adjusting or widening its concept and practice to take account of new risk related climate change; and, at the same time, a modification and widening of the climate change community approach in order to more fully incorporate concepts and experience from disaster risk management.

Disaster or emergency management was formerly dominated by considerations of disaster response and preparedness and was focused predominantly on large-scale events. Over the past 30 years this approach has evolved in favour of a more balanced framework that includes development based risk reduction, risk prevision and disaster recovery strategies and instruments and a greater importance on smaller scale, but more recurrent events. The accommodation of climate change will be but the latest in a series of ongoing changes to disaster risk and disaster concepts and practice over time (see Hewitt, 1983; Smith, 1996; Tobin and Montz, 1997; Blaikie et al, 1996; Hewitt, 1997; Wisner et al, 2004, Lavell, 2005; Gaillard, 2010, for background and review of some of these historical changes).

Climate change policy, strategy and implementation already uses language and terminology with increasing emphasis on the need for adaptation in the face of changing average climate and climate and weather extremes (Schipper and Burton, 2009). Increasing demand exists for assessment and promotion of disaster risk management practice that can contribute to climate change adaptation. This requires increasing synergy, merging and complementarity between these two currently and still largely differentiated practices, both of which seek greater human and environmental security.

Despite the recognition of the need to bridge disaster risk management and climate change adaptation, progress on the ground in terms of tangible integration of adaptation projects and planning processes based on the concepts of disaster risk management and sustainable development has been very limited (German Committee for Disaster Reduction, 2009; Lavell, 2009; UNFCCC, 2008; Cristoplos, 2008; VARG, 2006; Mitchell and Van Aalst, 2008; Tear Fund, 2008; Adger et al 2007).

Contributing causes of this lack of integration include differing conceptual and definitional bases, differing institutional and organizational arrangements, differing scientific origins and baseline literature, and differing understandings of causal relations and the relative importance of different risk factors (see Schipper and Burton, eds, 2009; Tear Fund, 2008, Mitchell and van Aalst, 2008). While recognizing that disaster risk management and climate change adaptation employ concepts and have objectives and approaches that only partially overlap, this report aims at assessing the literature with a view toward developing an interdisciplinary approach, hence a robust bridge between the two practices. The present chapter lays out the conceptual premises, key notions, definitions and assumptions with which the climate change and disaster risk management communities, and the sub-communities within these, operate. It seeks to establish the challenges, the gaps, contradictions, similarities, convergences and divergences from a conceptual and practical viewpoint arising from consideration of the well-established and evolving disaster risk management theory and practice and the more recent science of climate change adaptation.

1.1.3. Key Concepts

Our starting point is the search to establish a commonly acceptable, conceptual and definitional framework that may be used throughout this report, while recognizing the valid historical and intellectual reasons for the distinct concepts, frameworks, and terms associated with and used by the disaster risk management and climate change adaptation communities and their respective sub-communities (see Figure 1-1). These differences have on many occasions impeded a free flow of understanding and exchange between and even within the two fields (Schipper and Pelling, 2006; O'Brien et al, 2006). Here only basic parameters and guidelines for definition will be established. Subsequent chapters will amplify and sharpen the basic notions here presented, and provide information on the range of different definitions used in the literature, allowing the richness of conceptual analysis to come forth without unnecessary rigidity being imposed from the outset.

[INSERT FIGURE 1-1 HERE
Figure 1-1: The key concepts and scope of this report.]

1.1.3.1. Risk

Both climate change adaptation and disaster risk management search to reduce factors and modify contexts that contribute to climate-related risk while enabling sustainability in social and economic development. Accordingly, a useful starting point for conceptual convergence is to assure clarity about the concept of **disaster risk**, which is used in this study to refer probabilistically to the level of damage and loss associated with the future occurrence of a forecasted physical phenomenon or event (or sequence of events) and which is determined by the convolution of hazard and vulnerability factors (Cardona, 2004; Carter et al 2007; Schneider et al 2007; see the following sub-section for definition of these terms). This contrasts with other commonly used definitions where risk is defined as the probability of the occurrence of a particular type of physical event as is the case when referring to seismic, flood or hurricane "risk", for example.

1.1.3.2. Social Conditioning of Loss and Damage

Loss and damage are themselves a result of the magnitude, intensity and physical and temporal extent of a physical event interacting with socially constructed or determined conditions that commonly go under the name of "**vulnerability**", conditions that may be evaluated according to a variety of quantitative and qualitative metrics (Schneider et al 2007).

Exposure, widely used in disaster risk management studies but not defined in the more commonly used climate change glossaries (IPCC, 2007)**,** refers to the location of social and economic elements, population, infrastructure, production, culture, etc. in areas where physical events may be predicted to occur. Such physical events are typically denoted "**hazards**". That is to say, physical events per se are transposed into "**hazards"** where social elements are exposed to their potential damaging impacts. (see Smith, 1996; Tobin and Montz, 1997). This means that hazard is the latent threat associated with any type of physical event that may occur in a particular context, rather than the event itself. It is one of the defining components or factors of risk, a latent condition that announces future loss and damage.

The usage here reflects an emerging understanding that disaster risk, while embodying an objective, physical aspect, is fundamentally a "social construction", the result of social choice, constraints, social action and inaction. An example would be the decision or not to operate in a particular manner, to locate in a particular place and build in a particular fashion which is the product of varied and differing political, economic, cultural and psychologically induced considerations, perceptions and actions (see Section 1.3.x; Wisner et al., 2004; Douglas and Wildavsky, 1983; Weber 2006). While physical aspects help define the disaster risk problem, it is only through concerted human action and social decision making that risk may be managed.

Exposure as such is not risk. Exposure to potentially damaging physical events where not accompanied by so-called "vulnerability" of the exposed social elements will not lead to loss and damage. Differential levels of "vulnerability" will lead to differential levels of loss, even under similar conditions of exposure to physical events of a given magnitude.

Vulnerability originated in disaster risk management, as opposed to climate change adaptation, in the 1970s (see Baird et al, 1975; O'Keefe et al, 1976; Wisner et al 1977, quoted in Gaillard, 2010) and can be defined in terms of the susceptibility of humans, their livelihoods, assets and infrastructure to suffer loss and damage when faced with physical events of varying magnitudes. It highlights the conditions in society which pre-dispose particular groups of people to loss and harm. As Gaillard (2010) points out, despite a broad agreement amongst authors as to the basic definition, significant divergences of approach exist when applying the notion of vulnerability to analysis. Thus, in its earlier interpretation the concept referred to the social relations, processes and structures that lead people to be susceptible to loss or harm in the face of hazards or food shortage and examined macro scale structural and societal constraints. By contrast, engineers and earth scientists used the term vulnerability in computations of quantitative indices of potential losses to built structures (so-called structural vulnerability).

The fundamental importance of vulnerability to the disaster risk management and disaster risk communities may be seen in the way it helped reveal social factors in the explanation of risk, moving away from purely physical explanations of loss and damage (see Hewitt 1983 for an early critique of what he referred to as the "physicalist" interpretation of disaster).

In contrast, the IPCC definition of vulnerability refers to "the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity". This definition sees vulnerability as an outcome of climate change factors operating in a particular setting. Some authors have criticized this definition as leading to an emphasis on physical events as opposed to social factors in understanding vulnerability and risk (Kelman and Gaillard, 2008; Gaillard, 2010).

Underlying this tension is the recognition that characterizations of physical events by statistical distributions for specific periods of time (see Section 1.2 and Chapter 3 for details), are necessary but not sufficient for understanding disaster. The explicit recognition of the political, economic, social, cultural, and psychological elements of risk explains the use in this report of the phrase "extreme impacts" in addition to "extreme events" as a way to denote a key aspect of the problem. Depending on the context, physical extremes may or may not bring along extreme impacts; likewise, some extreme impacts may follow from events which in purely physical terms and in isolation from social context would not be defined as extreme. For example, the vast majority of disasters registered annually in particular disaster data bases are not associated with extreme physical events as defined probabilistically (see Section 1.2.x), but many have important and even extreme impacts for local and regional societies (see ISDR, 2009). These data bases include EM-DAT at the Centre for the Epidemiology of Disasters, University of Louvain (Centre for the Epidemiology of Disasters, 2008), and the DESINVENTAR data base used by ISDR and others to examine small and medium scale disaster occurrences and "extensive risk" in Latin America and Asia in particular (see ISDR, 2009; Corporación OSSO, 2008)

1.1.3.3. Recovering from Disaster Loss and Damage

The consequences of disaster and aspects relating to recovery following disaster are characterized by diverse concepts including coping, capacity, and resilience. Coping will be dealt with in some detail in Section 1.4.

As Gaillard (2010) points out**, resilience** has been used in disaster contexts since the 1970s (Torry, 1979) and has its origins in engineering (Gordon, 1979), ecology (Holling, 1973) and child psychology (Werner et al, 1971).

Common to its various uses, resilience refers to characteristics of society, social groups and individuals which, following trauma or initial crisis and impact, allow certain sectors and populations to recover with greater facility than others. In this sense it is related to the notion of elasticity or malleability, and maintenance of essential functions (see Section 1.4.3.2).

Although now commonly employed, the term is however subject to very diverse interpretations. These range from a more strict use in post impact situations through to its usage for depicting conditions at any point of the risk or disaster continuum, before, during, or post hazard impact. This confusion and the “borrowing” of concepts from other thematic and disciplinary areas has in fact led to the decision by some outstanding disaster risk experts to obviate its use and to consider “vulnerability” and “lack of capacities” as sufficient in explaining differential success in recovery (Wisner et al., 2004: 12). Under this formula, vulnerability both potentiates original loss and also impedes recovery. Finally, resilience, “bouncing back”, and its conceptual “cousin”, coping (see Section 1.4), or “getting by” have been criticized as emphasizing a status quo, often unjustifiable prior situation, i.e., “surviving”, as opposed to “bouncing forward” and “thriving”.

Capacity and capacity building are important concepts for climate change adaptation and also for disaster risk management. Capacity involves access to and use of social, economic/ livelihood related and natural resource-based, psychological, cultural resources, conditions and characteristics that permit society at large, organizations and institutions and groups of people to reduce susceptibility to loss and harm from extreme events and extreme impacts. Introduced into disaster management work in the late 1980s by Anderson and Woodrow (1989) as a means of shifting analytical balance from negative aspects of vulnerability to positive actions by people, the notion of capacity is fundamental to imagining and designing a positive movement in favour of risk reduction and adaptation. Capacity may be used in the context of pre-impact risk reduction, response, coping, and recovery.

1.1.3.4. Approaches or Concepts for Understanding and Intervening in Risk

In establishing the boundaries of phenomena and social processes that concern disaster risk management and climate change adaptation, two key questions arise: 1) to what degree should the focus be on exceptional events (a physicalist approach) as distinct from the routine, daily occurrences (emphasizing social context); and 2) what is the appropriate territorial scale that ought to be considered?

1.1.3.4.1. Exceptionality, extremity, and the every day or quotidien

Schemes and interpretations based on physical causes of loss and damage have been referred to as “physicalist” (see Hewitt, 1983) whilst notions developed around normal, everyday-life risk factors, which are much favoured by many disaster risk specialists can be considered “comprehensive” (embracing the physical and the social). The latter were a major contributing factor in the development of the so-called “vulnerability paradigm” for understanding disaster (Wisner et al, 2004; Hewitt, 1983, 1996). Additionally, the more recent discussion on the role of small and medium scale disasters and so-called “extensive risk” (ISDR, 2009) provides a further argument for the need to deal integrally with the problem of loss and damage, looking across the different scales of experience both in human and physical worlds, in order to advance adaptation. The design of mechanisms and strategies based on the removal of every day or chronic risk factors (Sen, 1983; World Bank 2001), as opposed to actions based solely on the “exceptional” and “extreme” is one obvious corollary of this approach. The ability to deal with risk, crisis, and change is influenced by an individual’s life experience with smaller scale occurrences. Climate change and its attendant additional risks and opportunities will inevitably be understood and responded to at the scale of the individual household in the context of many other changes, including economic, political, technological, and cultural ones (see Box 1-1 and Section 1.4.3.1).

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Box 1-1. Title TBD

Joseph is eighty years old. He and his father and his grandfather have witnessed many changes. Their homes have shifted back and forth from the steep slopes of the South Pare Mountains at 1,500 m to the plains 20 km away, near the Pangani River at 600 m. What do "changes" (mabadiliko) mean to someone whose father saw the Germans and English fight during the First World War and whose grandfather defended against Maasai cattle raids when Victoria was still Queen?

Joseph outlived the British time. He saw African Socialism come and go after Independence. A road was constructed parallel to the old German rail line. Successions of commercial crops were dominant during his long life, some grown in the lowlands on plantations (sisal, kapok, and sugar), and some in the mountains (coffee, cardamom, ginger). He has seen staple foods change as maize became more popular than cassava and bananas. Land cover has also changed. Forest retreated, but new trees were grown on farms. Pasture grasses changed as the government banned seasonal burning. The Pangani River was dammed, and the electricity company decides how much water people can take for irrigation. Hospitals and schools have been built. Insecticide treated bed nets recently arrived for the children and pregnant mothers.

Joseph has nine plots of land at different altitudes spanning the distance from mountain to plane, and he keeps in touch with his children who work them by mobile phone. What is "climate change" (mabadiliko ya tabia nchi) to Joseph? He has suffered and benefited from many changes. He has lived through many droughts with periods of hunger, witnessed floods, and also seen landslides in the mountains. He is skilled at seizing opportunities from changes – small and large: "Mabadiliko bora kuliko mapumziko" (Change is better than resting).

The provenance is taken from an original field work interview undertaken by Ben Wisner in November 2009 in Same District, Kilimanjaro Region, Tanzania in the context of the U.S. National Science Foundation funded research project "Linking Local Knowledge and Local Institutions for the Study of Adaptive Capacity to Climate Change: Participatory GIS in Northern Tanzania."

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1.1.3.4.2. Scale and disaster risk

According to one view, disaster risk or, in the case of this study, climate related risk is most adequately depicted, measured and monitored at the local or micro level where the concrete interaction of hazard and vulnerability are worked out "on the ground" (Lavell, 2005). At the same time it is accepted that risk construction processes are not limited to specifically local or micro processes but, rather, are related to diverse environmental, economic and social and ideological influences whose sources are to be found at scales from the international through to the national, sub-national and local levels, each in constant flux (Wisner et al, 2004). Thus disaster risk management and adaptation policy, strategies and instruments will only be successful where understanding and intervention is based on multi-scale principles and where phenomena and actions at local, sub-national, national and international scales are construed in interacting ways (Lavell, 2002) (see Section 1.5 and Chapters 5-9).

1.1.4. A Basis for Advancing Holistic, Integrated, and Interdisciplinary Understanding

It can be concluded from the earlier discussion that a more holistic, integrated, interdisciplinary approach to assessment than currently exits is needed to bridge the gap between the (at times) different approaches and visions provided by the climate change adaptation and disaster risk management communities. This refers to both the ways physical extremes and non-extremes are viewed and the manner in which vulnerability and changes and challenges in everyday life are depicted and the way exceptional circumstances are characterized. Such an approach would probably recognize the participatory methods and basic decentralization principles inherent in both climate change adaptation and disaster risk management while transcending the tendency to divide the world up for analytical and intervention ends, which has very limited utility.

1.2. Extreme Events, Extreme Impacts, Disasters, and their Management for Advancing Climate Change Adaptation

1.2.1. Extreme Events, Extreme Impacts, and Disasters

The objective of this section is to amplify on the outlined definitions and distinctions among extreme events, extreme impacts, and disasters given in Section 1.1 and discussed further in Chapter 3, with a view toward clarifying the role and interactions of physical versus social processes.

Discussion and definitions of "extreme events" and their relationship with "extreme impacts" and "disasters" are common in both the disaster risk and climate change adaptation literature. Perspectives on extreme events vary widely, from a statistical definition of measured physical attributes of phenomena used by natural scientists (see Chapter 3) to a concern with the deterioration of social systems often expressed qualitatively by social scientists (see Chapters X). In attempting to align both perspectives, a U.S. National Science Foundation (NSF) "Workshop on Extreme Events: Developing a Research Agenda for the 21st Century" concluded in 2000 that any successful effort to conceptualize "*extreme events" as a researchable issue will rest on an explicit awareness of the context…*" The context reflects an agenda focused around improving human welfare.

The definition of "extreme event" offered at the same NSF workshop covers both physical attributes of an initial event and its social and physical impacts:

> "*...an occurrence (physical, author's note) that with respect to some class of related occurrences, is eithernotable, rare, unique, profound, or otherwise significant in terms of its impacts, effects, or outcomes*."

And, also bridging the divide between extreme events and extreme impacts, Easterling et al. (2000) define extreme climate events *as "those climate events causing extraordinary economic and social (loss of life or livelihood) damage*".

In contrast, the IPCC definitions in the Working Group I, Working Group II, and Synthesis reports of the Fourth Assessment Report are purely physical and focused on the initial event, although slightly different in each case. For example, the glossary of the Synthesis report defines an extreme weather event as follows:

> '*An event that is rare at a particular place and time of year. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense...When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).*'

This tension between the purely physical and social impact perspectives was emphasized in social science literature in the 1970s and 1980s as articulated by Kenneth Hewitt (1983) who "*castigated hazards researchers for the overwhelming attention devoted to geophysical processes and the neglect of societal forces*" (Tobin and Montz, 1997). In considering the food deficit problem, Wisner et al (2004) note that analysts still grant a significant role "*to 'extreme' natural events which focuses attention on unpredictable nature… meaning (they) can avoid the analysis of how the history of vulnerability….operates to provide the context for the triggering event*".

The general definition of a weather or climate extreme and its link with an 'extreme impact' depends strongly on context, reflecting both the degree to which populations or ecosystems are located in the path of the extreme (exposure) and the underlying vulnerability or susceptibility to damage of these populations. In the following discussion, quantitative definitions of different classes of extreme events are explored before considering what characteristics determine that an impact is extreme, how climate change may affect our understanding of extreme events and extreme impacts, and how these should be considered and communicated.

1.2.2. Extreme Events Defined in Physical Terms

Weather can be defined as '*the state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity, and barometric pressure*' while **climate** is '*the meteorological conditions, including temperature, precipitation, and wind, that characteristically prevail in a particular regiǿn* (http://www.thefreedictionary.com)'.

In addition to providing a long-term mean of weather, 'Climate' characterizes the full spectrum of means and extremes associated with 'unusual' and unusually persistent weather. In probabilistic terms, the outer tail of this annual variance (i.e., extending beyond the 90th or 10th - percentiles of the underlying distribution) reflects the infrequent extremes, the weather events, and the climate states that by virtue of their scarcity may have damaging impacts on human settlements, infrastructure, lives, and ecosystems which lack adequate resilience and resistance to them. Scarcity is specific to location and climate contexts: a month of temperatures corresponding to the expected Spring climatological daily maximum in Chennai would be termed a heat wave in France; the precipitation of a monthly maximum tropical afternoon in Kuala Lumpur would lead to a flash flood in Mongolia; a snow storm expected every year in New York would provoke a disaster when it occurs in southern China.

Out of the simple raw materials of precipitation, winds, and temperatures emerges a wide range of potential extreme weather events. In the extreme, water, whether it falls as rain, freezing rain (rain falling through a surface layer below freezing), snow or hail, can lead to damaging consequences (Peters et al., 2001). The absence of precipitation can also be a climate extreme (McKee et al., 1993). Extreme surface winds are chiefly associated with structured storm circulations (Emanuel, 2003, Clark et al., 2006, von Ahn et al., 2004). Each storm type, including tropical and extra-tropical storms, presents a spectrum of size, forward speed, and intensity that, in the tail of the distribution of such characteristics, drives damaging extremes of wind and precipitation.

The full range of climate extremes reflects the interactions of atmospheric temperatures, motions, and precipitations over a very wide range of timescales, spanning up to eight orders of magnitude, from the short-lived passage of an intense tornado to a multi-year drought. The behavior of the atmosphere is also highly interlinked with that of the hydrosphere, ocean, and terrestrial environment so that extreme (or sometimes non-extreme) atmospheric events may cause (or contribute to) other rare physical events such as extreme sea levels, river levels, landslides and avalanches. Of course they also can lead to non-rare or non-extreme manifestations of such events.

Here the distinction between the initial physical event and its impact becomes critically important. Whether climate and weather extremes cause extremes of physical surface phenomena, like landslides, avalanches, and river levels, depends on the physical and ecological context in which the initial event occurs, and often the pre-existing human management and reconfiguration of that context. Some literature (Easterling et al.,2000) reserves the term "extreme event" for the initial physical phenomenon; some includes the physical impacts, like flooding, which follow from the initial event even though the latter can also include a human factor; and some literature uses this term to refer to the entire spectrum of outcomes including the initial event and its effects on humans, society, and ecosystems. In this report, we use "extreme event" to refer to physical phenomena including some, like flooding, which may have a human component to causation. We contextualize "impact" to include: a) changes in the natural physical environment, like flooding, beach erosion from storms and mudslides; b) changes in ecosystems, such as the , blow-down of forests in hurricanes, the bleaching of coral reefs in warming events; and c) human or societal loss and damage. An "extreme impact" reflects highly significant consequences.

Among the more important physical extremes or physical impacts deriving from climate and weather interacting with the hydrosphere, cryosphere, and other aspects of the geosphere and biosphere, the following are particularly relevant to this report:

- Exceptionally high or low sea surface temperatures affecting sea ice formation (Gordon et al., 2000) and biological systems like coral reefs (Brown, 1997).

- Large cyclonic storms, with their reduced central pressures and persistent winds, generating positive and negative storm surges in both the sea and large lakes which become amplified on long shoaling coasts (Xie et al., 2004).
- Rivers reflect the most volatile component of the hydrosphere (Henshaw et al., 2000). Flows exceeding the 1- or 2-year maximum typically expand beyond the natural channel to produce 'floods' (Gurnell and Petts, 1995). Extreme flows arise from intense precipitation, spring thaw of accumulated winter snowfall, or an outburst from an ice, landslide or artificially dammed lake. River systems are tuned to react to particular durations of intense precipitation, with steep short mountain streams responding to rainfall totals over a few hours, while peak flows on major continental rivers reflect precipitation extremes of weeks (Wheater, 2002). Here the history of human management is an additional contributory cause of extremity, in particular in the urban environment, where impermeable surfaces lead to rapid run-off with little infiltration (Wheater, 2002).
- Long term reductions in precipitation, exacerbating human groundwater extraction, reduce ground water levels, causing spring-fed rivers to disappear (Konikow and Kendy, 2005).
- For glacial rivers, rising temperatures lead to increased summer meltwater flow until a glacier finally dwindles, after which flow will be significantly reduced in hot dry seasons (potentially creating unprecedented low flow extremes), as anticipated in regions such as Bolivia and central Asia (Rees and Collins, 2006).
- At the interface of the hydrosphere and geosphere, landslides (Dhakal and Sidle, 2004) are triggered by raised ground water levels after excess rainfall or melting permafrost and glacial retreat.

A variety of feedbacks and other interactions connect extreme events and ecological responses in a way that may amplify such extremes events or lead to additional physical impacts. For example, reductions in soil moisture intensify heat waves (Seneviratne 2006), while droughts following rainy seasons turn vegetation into fuel that can be consumed in wildfires (Westerling and Swetman, 2003).

1.2.3. Extreme Impacts

Extreme impacts to human, biological or physical systems, can be the result of a single extreme event, a compound of extremes or non-extremes, or simply the persistence of conditions, such as those that lead to drought. Whether an extreme event results in extreme impacts to physical, human, and ecological systems depends, as has been said previously, on the degree of exposure and vulnerability and lack of resilience or resistance, in addition to the intensity of the physical event (see Box 1-2). Similarly, the human, societal, physical and ecological context in which non-extreme events occur determines whether or not extreme impacts result (see Section 1.1 and Box 1-1).

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Box 1-2. Impact Determined by Previous State of the Environment

The impact of an extreme event can be strongly determined by the prevailing condition of the environment. Since the late 1990s Gangwon Province in South Korea has experienced several severe wildfires as a result of droughts, as in 1996, 2000 and 2005 (NEMA, 2009). These resulted in deforestation, especially on the steep mountainsides. Therefore, those areas were left with a high potential for landslide risk in case of heavy rainfalls.

In 2006, Typhoon Ewiniar struck Korea. As the typhoon filled and weakened, heavy and persistent rainfall continued in the mountainous northeastern part of the country, especially in Gangwon Province, with 90mm of hourly rainfall at Pyeongchang (NEMA, 2007). The rainfall led to severe landslides, which brought a great amount of debris into streams, and consequently resulted in significant flooding.

In contrast, other neighboring areas with similarly intense precipitation suffered from much less secondary mass movement or consequential flooding, because they had not had the previous degradation of the landscape or were better prepared after experiencing severe typhoons such as Rusa in 2002 and Maemi in 2003 (NEMA, 2007).

Since the damaged areas were neither highly populated, nor farmed, the total quanitifable damage was not high enough for the event to be classified as a major disaster. However, damage to the natural ecosystem and to infrastructure were very severe: rivers, hill slopes, and roads were devastated, and the rural population lost its means of livelihood. The Korean government was prevailed upon to amend the law for disaster and safety management and to declare the affected region a major disaster area, thereby facilitating financial assistance. After this compound disaster, the government and the local people worked diligently toward recovery of the damaged areas, starting a program to control soil erosion and to build dams in areas of potential risk to prevent debris from flowing downstream (Gangwon Province, 2007).

_____ END BOX 1-2 HERE _____

In the climate change and adaptation literature, extreme events are often considered in strictly physical terms (Easterling et al., 2000). In contrast, in the disaster risk community, “extreme” refers to levels of damage and loss, and the notion of “event” increasingly takes on a social connotation (Thomalla et al., 2006).

Metrics to quantify extreme impacts may include, among others (Below et al., 2009):

i) human casualties and injuries
ii) numbers of permanently or temporarily displaced people
iii) impacts to properties, measured in terms of numbers of buildings damaged or destroyed
iv) impacts to infrastructure and lifelines
v) financial or economic loss
vi) duration of the above impacts.

Both human and natural systems will be largely unaffected by a wide spectrum of weather. Extreme impacts arise due to the lack of resistance and resilience in the face of the rarest individual extremes and more common smaller scale events, or to a concatenation of less extreme events. Trees, like indigenous building styles, have evolved (or grow) to withstand extremes expected every 10-50 years, but not extremes that lie beyond their average lifespan of 100-500 years, reflecting the inherent cost-benefit ratio of developing additional levels of protection (Ostertag et al., 2005). Tree susceptibility to being uprooted or felled by extreme winds, for example, is strongly species dependent, with evidence that indigenous species adapted to a particular climatology of extreme winds are more resilient than species imported from lower wind hazard regions (Canham et al., 2001).

Human systems are also explicitly designed to withstand expected extremes. On the island of Guam, within the most active and intense zone of tropical cyclone activity on Earth, buildings are built to the the most stringent ordinary building wind design code in the world, requiring a bunker style construction able to withstand wind speeds of 76metres/second as expected in this location every few decades (International Building Codes, 2003). However, even for the same return period of an extreme (e.g., a 100-year storm return period), climate conditioning may vary from place to place (reflecting the relationship between extreme wind and return period). In the tropics, without any source of high wind speeds other than rare tropical cyclones, indigenous vernacular building practices are less likely to be resilient than at mid latitudes (Minor, 1983).

Communities accustomed to periodic droughts employ wells, boreholes, pumps, dams and irrigation systems. Those with houses exposed to excessive seasonal heat have developed passive cooling systems, or acquire air conditioning. In regions unaccustomed to heat waves, the absence of such systems, in particular in the houses of the most vulnerable elderly or sick, contributes to excess mortality, as in Paris, France in 2003 (Vandentorren et al., 2004).

1.2.4. Distinguishing Disasters from Extreme Events and Extreme Impacts

Disasters are defined in Section 1.1.1 as extreme impacts associated with a severe disruption of the normal, routine functioning of the affected society. Some definitions of ‘disasters’ for the purposes of tabulating occurrences rely only on exceedances of thresholds of numbers of killed or injured, or repair costs (see Below et al., 2009). More contextually, societal impacts resulting from weather or climate events become a disaster when they surpass thresholds in at least one of three dimensions: spatial (so that damages cannot be restored from proximate capacity), temporal (so that recovery becomes frustrated by further damages) , and intensity of impact on the affected population (undermining the capacity of the society to repair itself; Alexander, 1993). For example, Tobin and Montz, (1997) contrast everyday or chronic risk with "*threats and levels of damage that can overwhelm whole communities or cripple aspects of every day life-such are the features of disasters and catastrophes*". While extreme physical events may be the principle trigger of many disasters, a disaster may also arise from a concatenation of physical, ecological and social reactions to lesser physical events (see Box 1-2). Disasters may be exacerbated by pre-existing social processes and events, such as financial crises, trade policies, wars, disease outbreaks etc. Evacuation or migration away from the site of one disaster can leave a population much more vulnerable to further disasters. In focusing on the social context of disasters, Quarantelli (1986) proposed the use of the notion of 'disaster occurrences or occasions' in place of 'events'.

The term "event" also does not capture the full range of characteristics of impacts and disasters, because it does not reflect the compounding of outcomes from successive physical phenomena, e.g., footprints from a succession of serial storms tracking across the same region which can generate disasters. The circulation in an entire hemisphere can lock into a stable configuration (teleconnect) for periods up to 6 weeks, as in August and September 2004, when both the western equatorial North Atlantic hurricane track and the western Pacific typhoon track became set, leading to four major hurricanes making landfall on Florida and four typhoons striking Japan (Kim et al., 2005; Bell et al., 2004). Atmospheric teleconnections also relate to the principal drivers of oceanic sea surface temperatures, in particular ENSO. Sometimes locations affected in the same weather event can be far apart, as for example when extreme precipitation fell in the headwaters of different river systems (see European floods of 2002 Ulbrich et al., 2003).

The aftermath of one extreme may precondition successor events, leading to disaster. High groundwater levels and river flows can persist for months, increasing the probability of a later storm causing flooding. The 1997-1998, El Nino, that led to heavy rains across Honduras causing saturated soils, ahead of the arrival of the stalled intense 1998 Hurricane Mitch that in turn triggered massive landslides and destructive floods (Smith et al., 2002). Periods of high rainfall followed by droughts create the conditions for wildfires, which in turn promote soil run off and landslides when the rains return (Cannon et al., 2001). However, extremes can also interact to reduce disaster risk. The wind-driven waves in a hurricane bring colder waters to the surface from beneath the thermocline and for the next month, any cyclone whose path follows too closely will tend to lose intensity (Emanuel, 2001).

1.2.4.1. Extremes in a Changing Climate

Climate change is expected to alter both the intensity and frequency of extreme (and non-extreme) events, and thereby alter their distribution and concentration in space and time (see Section 1.2.5, Box 1-3, and Chapter 3). Potential outcomes in terms of particular extreme impacts and disasters are discussed in succeeding chapters. A key issue to bear in mind is that an extreme event or a disaster may result from a succession of smaller events, or a moderate event superimposed onto a gradual trend, such as would occur in a changing climate. For example, in the future, a storm surge with a ten year return period superimposed on a higher sea level could have the same consequences as a disastrous storm surge flood with a hundred-year return period occurring today (see Section 1.2.5), depending on the level of learning and adaptation in the interim. Even without the additional contribution of sea level rise, disasters sometimes result from the interactions between two unrelated geophysical phenomena such as a moderate storm surge coinciding with an extreme spring tide (as in the most catastrophic UK storm surge flood of the past 500 years in 1607 - Horsburgh and Horritt, 2006). Climate change may alter both surges and sea levels, compounding such extremes. Novel combinations of events, such as an earthquake occurring coincident with high groundwater levels, or a tsunami superimposed on higher sea level, may also cause unprecedented outcomes.

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Box 1-3. Example of Complex Ways in which Extreme Events, Long-Term Trends, and High Vulnerability Interact to Produce Extreme Impacts

Sahel is located on the southern margins of the Sahara desert, where the ecology and the climate start to make settlement possible again (Nyong et al., 2007). Drought in Sahel dates back to early times, reflecting the fact that the southern boundary of the desert fluctuates. The most prominent and severe recent drought was in the early 1970s (Hulme, 1992, 1996, 2001, Batterbury and Warren, 2001) when hundreds of thousands of people and millions of animals died (Mortimore, 1998). The prolonged period of reduced rainfall (down by 20-30%) that began in the early 1970s is still in progress (Le Houérou, 1996, Nicholson, 1986, 1989, 1993) and reflects regional shifts in rainfall patterns also affected by ENSO (Folland et al., 1986; Ward, 1998). . At the same time, the population in the area has increased rapidly with an average annual growth of 2.6 percent (UNPP, 2006). This increase, along with social conditioning and social deficit,, combined with the persistent droughts, appears to be a main cause of degradation of ecosystems, by humans over-using natural resources in the region through overgrazing**,** deforestation, overcultivation, intensive irrigation, and poor land management (Olssona et al. 2005, Ezra, 2001, Nicholson, et al. 1998). The loss of vegetation has been linked to increased surface albedo, increased dust generation, and reduced productivity of the land (Nicholson, et al. 1998). The combined pressures on the fragile environment and severe droughts made the society and ecosystems more vulnerable to impacts from extreme events.

According to the report of Africa Committee on Sustainable Development under the aegis of United Nations Economic Commission for Africa (UN-ECA Report, 2007), drought and floods induced 80 percent of loss of life and 70 percent of economic losses linked to climate hazards in Sub-Saharan Africa. The drought of 2001–03 resulted in a food deficit of 3.3 million tons, with an estimated 14.4 million people in need of assistance in the sub-region. Major rivers and lakes highly sensitive to rainfall variability are severely affected by water stress, weakening the potential for hydropower generation. The population threatened by migration in response to desertification is estimated at 135 million people, 60 million of whom are in Sub-Saharan Africa, the Sahel and the Horn of Africa. Migration paths are expected to be towards Northern Africa and Europe**.**

During recent decades, eastern Africa has experienced high rainfall variability, (Schreck and Semazzi, 2004). The persistent and severe droughts of the 1970s and 1980s and those occurring during 2001-2003 have been associated with socioeconomic and environmental disasters including loss of life, poverty, famine, mass migration of pastoralists and farmers, environmental refugees, shortage of food, water and energy (UNEP, 2002, UNECA, 2007)

_____ END BOX 1-3 HERE _____

1.3. Disaster Risk Management, Reduction, and Transfer

The disaster risk management community has developed key concepts and methods for managing, reducing, and transferring or sharing risk. These concepts must evolve in order to take account of the ways changing climate and other environmental and social conditions such as the state of development, income levels, and distribution of resources within a society may affect management schemes and challenges.

This section will first review and critique the probabilistic risk analysis framework that provides the conceptual underpinnings for much of the literature on risk management, reduction, and transfer. It will then summarize how risk management, reduction, and transfer are addressed in both the literature and practice of disaster risk management and climate change adaptation, and suggest how considerations of climate change might affect disaster risk management. This section emphasizes conceptual frameworks, not because they are necessarily commonly implemented in pure form nor currently available to all practioners, but rather because they support a more thorough understanding of current practice and potential improvements. The section does conclude with a review of such current practice in both developed and developing countries.

1.3.1. Probabilistic Risk Analysis

Probabilistic Risk Analysis (Beford and Cooke, 2001) provides an important set of concepts used in a wide range of economic, environmental, engineering, medical, and other applications to estimate various risks and to evaluate alternative options for reducing and managing them. The disaster risk management and climate change literatures also use this framework. In its simplest form, the approach defines risk as the product of the probability that some event will occur and the probability of adverse consequences of some magnitude resulting from the interactions of that event with humans, their societies, and their physical artifacts. For instance, the risk a community faces from flooding from a nearby river might be calculated as the likelihood of the river rising high enough to inundate the town multiplied by the likelihood that such flooding would kill and injure a certain number of people, cause a particular amount of damage to the community's buildings and possessions, and disrupt the community's economic livelihood for a particular period of time. The community could also evaluate various options for reducing risks by comparing their effect on the likelihood and magnitude of the adverse consequences from any given flood.

A community will typically face many types of events and potential consequences. Thus, the community's overall risk can be written as

$$\text{Total Risk} = \sum_{\substack{\text{All Events}\\ \text{All Consequences}}} \text{Prob(Event)} \times \text{Prob(Consequence)} \qquad (1)$$

The disaster risk management literature focuses on actions communities can take to reduce and manage risk by lowering the probability of adverse consequences from events (the second term on the right-hand side of Eq 1), and by transfering or sharing risks through mechanisms such as insurance. In the context of Eq 1, such risk transfer or sharing would reduce the net consequences to a particular individual or community of some event while increasing it for others. As will be discussed in more detail below and throughout this report, disaster risk management generally regards the probability of events– such as hurricanes, droughts, and heavy rainfall -- as beyond human control. In general, anthropogenic climate change may affect the probability of such events, though it is important to note that the relation between greenhouse gas emissions and the probabilities over space and time of particular types of events, e.g., intense precipition, tropical storms, or droughts, remains uncertain (IPCC 2007, Table SPM-3). In the broadest context, policies to address climate change can reduce risk both by limiting atmospheric concentrations of greenhouse gases (mitigation) and taking actions that limit the consequences of such events (adaptation). However, this report focuses only on the latter set of actions.

1.3.2. Challenges in Implementing the Probabilistic Risk Framework

Probabilistic risk analysis offers a powerful and elegant framework, but there exist numerous challenges to implementing it for disaster risk management and climate change adaptation. As will be described throughout this chapter and report, many communities lack the training and data to implement this framework in practice. But even in the most favorable real-world situations managing the risks created by extremes and disasters poses fundamental problems of estimating probabilities of both events and consequences as well as of risk communication. This subsection will address these two challenges.

1.3.2.1. Challenge of Imprecise Probabilities

The probabilistic risk management framework applies to events and their consequences of all types and of all magnitudes. This report focuses on reducing and managing the risks associated with extreme events and the extreme consequences of less extreme events. Such extremes pose a particular set of challenges for the probabilistic risk analysis framework because their relative infrequency often makes it difficult to obtain adequate data to estimate the probabilities used in Eq (1).

The likelihood of extreme events is most commonly described by the mean interval expected between one such event and its recurrance. For example, one might speak of a 100-year flood or a 50-year windstorm. More formally, these intervals are inversely proportional to the 'annual exceedence probability,' the likelihood that an event exceeding some magnitude occurs in any given year. Thus the 100-year flood has a 1% chance of occurring in any given year, though this translates into a 63% chance of occurring within any 100-year period because probabilities are not strictly addiive.

The larger question of the return period of an event cannot be answered without providing some additional spatial context. A typhoon has just made landfall in Vietnam. What is the 'events' return period? Is it the 20 year return period for an intense tropical cyclone making landfall somewhere on the coast of Vietnam, or the 200 year return period for a particular intensity storm making landfall within 50km of Hanoi? Or is it the ten-year return period for an event of this magnitude of loss? Furthermore across the footprint of a spatially extensive event, the extreme will likely have different point return periods.

These procedures still leave estimates of the probability of extreme events more imprecise than estimates of the probability of less extreme events. In addition, the probability of such extreme events will in general change over time in ways that may prove difficult to predict. For example, paleoclimate evidence suggests that before any anthropogenic climate change the frequency of large Atlantic hurricanes changes over time periods of decades and centuries. Anthropogenic climate change significantly exacerbates this already difficult estimation challenge, since it may generally alter such frequencies, intensities, and consequences in difficult-to-predict ways (Chapter 3; IPCC 2007; NRC 2009; TRB 2008).

There are, however, two ways of substituting for the absence of a suitable data time series: either by pooling independent observations (see Milly et al, 2002) or by inferring that changes at short return periods mimic changes in extremes (although the absence of evidence for a change at short return periods does not prove that the tail of extremes remains unaltered; Frei and Schar, 2001).

In addition, there are perhaps even more difficult challenges in estimating the probabilities of extreme consequences since these involve predicting the behavior of complex human systems under stressful and potentially novel conditions. Section 1.4.4.1 describes some of the challenges system complexity may pose for effective risk assessment.

The disaster risk management and climate change communtities communities have explored a variety of methods to help support decisions when it proves difficult or impossible to accurately estimate probabilities of events and of the adverse consequences suffered by the human systems with which these events interact. Qualitative scenario methods are often used for climate change adaptation(Parson et. al. 2007) and DRM. As described in Section 1.3.5.1, the probabailistic risk analysis can often be implemented in situations in which the probabilities are imprecise by employing ranges of values or sets of distributions, rather than single values or single best-estimate distributions (Morgan et. al. 2009).

1.3.2.2. Cognitive Barriers to Effective Communication about Extremes

A second fundamental challenge is that the key concepts underlying probabilist risk analysis – probabilies and risk – often prove difficult for people to communicate and understand. In particular, the judgment and decision-making literature suggests various cognitive barriers that make it more difficult for individuals and organizations to properly assimilate and respond to information about low probability events. Effective disaster risk management and climate change adaptation must thus address these barriers. Effective risk communication requires a process of exchanging, integrating and sharing knowledge and information about climate-related risks among all stakeholder groups: scientists, policy makers, private firms, non governmental organizations, media, and the public.

As described in the judgment and decision-making literature, the concepts of disaster, risk, and disaster risk management have very different meanings and interpretations for scientists and nonscientists. Experts in the private and public sectors often use the probabilitistic risk analysis framework. Within this framework, disasters are a statistical concept that combines probability and consequences, in conjunction with conditions of vulnerability. In contrast, the general public, politicians, and the media are more likely to focus on the concrete adverse consequences of such events, absent from the probabilistic context. To the extent that they respond to risk information transmitted in probabilistic form, they often do so in ways that diverge sharply from formal probability theory. The understanding of risks and extreme events by climate scientists are based in large part on analytic processing, as these experts have been trained in the necessary analytic tools and have the necessary input required for these tools.

Nonscientists, on the other hand, rely more on more readily available and more easily processed information. These gaps between scientist and nonscientist understanding of extreme events present important communication challenges (Weber and Stern, 2010).

1.3.2.2.1. Nonscientists' estimations of risk and extremes

Climate scientists use careful observations of phenomena to collect data over time, which are incorporated into models to project future states of the system. The average person predicts the likelihood of encountering an event in the future by consulting their past experiences with such events. The "availability" heuristic (i.e., useful shortcut) is commonly applied, in which the likelihood of an event is judged by the ease with which past instances can be brought to mind (Tversky and Kahneman, 1979). Extreme events, by definition, have a low probability of being represented in people's past experience and thus will be relatively unavailable. They will essentially be ignored unless and until they do happen to occur, as in the case of a hundred-year flood (Hertwig et al., 2004). For extreme events with severe and thus memorable consequences, people's estimates of their risks will, at least temporarily, become inflated (Weber, Shafir, Blais, 2004).

Nonscientists' judgments of risk are influenced more by emotional reactions to events (e.g., feelings of fear and loss of control) than by analytic assessments of their likelihood (Loewenstein et al., 2001). When expert assessment provides people with predictions about extreme events, in part to circumvent the problem that such events may not be available in the public's attention because of a paucity of past personal experience with them, people frequently ignore such forecasts if the extreme event fails to elicit strong emotional reactions, but will also overreact to such forecasts when the events elicit feelings of fear or dread (Weber, 2006).

1.3.2.2.2. Asymmetric reactions to gains and losses

Statistical theories and concepts related to dispersion or extremity of events treat the direction of deviations from average conditions or central tendency in a symmetric fashion. In contrast, the reactions of the general public, politicians, and the media are typically far stronger to deviations in the negative direction (perceived losses) than to deviations in the positive direction (perceived gains) (Kahneman and Tversky, 1979). Both imagined and experienced negative extreme events capture individual and societal attention and resources, as there is strong motivation to reduce the likelihood or impact of such events.

1.3.2.2.3. Influence of culture and ideology

The perceptions of risks and extremes by nonscientists are not only influenced by the cognitive shortcuts with which unaided and untrained human information processors circumvent limited attention and processing capacity (Kahneman and Tversky, 1979), but also by motivational factors that can introduce differences in perceptions and reactions as the result of variations in values and beliefs. Which extreme events are seen as threats or risks worthy of attention and reaction, and which extreme events are essentially ignored often differs between groups. People's worldview and political ideology guide attention towards events that threaten their desired social order (Weber, 2010). They also influence which sources of expert forecasts of extreme climate events will be trusted. Different groups put their trust into different organizations, from national meteorological services to independent farm organizations to the IPCC.

Factual information interacts with social, institutional, and cultural processes in ways that may amplify or attenuate public perceptions of risks and extreme events (Kasperson et al., 1988). Evidence from the health literature, the social psychological literature, and the risk communication literature suggests that these social and cultural risk amplification processes modify perceptions of risk in ways that may generally be socially adaptive, but can also bias reactions in socially undesirable ways in specific instances (American Psychological Association, 2009).

1.3.3 Current Framework for Disaster Risk Management

Disaster risk management primarily addresses the complex mix of social, economic, political, cultural, technical, and others factors that affect the consequences of a given event or events as well as efforts to reduce and manage those consequences. The field has evolved significantly over recent decades and offers a range of strategies, approaches, definitions and concepts which are briefly reviewed here.

Consistent with Eq (1) and following on from the basic definition given in Section 1.1, disaster risk itself is defined as "the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions."

The word disaster, when used to describe contexts associated with the impact of damaging physical phenomena, has been defined in many different ways (Sections 1.1 and 1.2 provide elements for defining disaster). The International Strategy for Disaster Reduction (UNISDR) refers to contexts where there is:

> "*a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources*" (UNISDR, 2009).

ISDR also presents the important clarification that a *"disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk."*

Despite criticisms that have been made of this and other disaster definitions, and complexities and redundancies raised by concepts like "hazard", "vulnerability" and "coping" (see Sections 1.1 and 1.4), the ISDR approach is sufficiently explicit and comprehensive to serve an an acceptable starting point for consideration of disaster risk management and reduction goals and processes.

Over the last fifty years the disaster intervention problematic has undergone very significant changes, increasingly adopting a probabilistic risk management framework, as opposed solely to a focus on specific occurances and reactions and responses to disasters, and increasingly emphasizing proactive in addition to reactive responses to these risks, favouring risk reduction, prevention and mitigation and with increasingly stronger, if as yet insufficient, links to development planning. Reactive approaches based on disaster management and response principles were captured under the terminology "Disaster" or "Emergency Management". This movement and transformation, which is differentiated in its level of advance on a regional and national level, and which is still more developed conceptually than on the ground, has led to the gradual, ongoing disappearance of the Disaster Management term as such and the emergence of the more comprehensive notion of Disaster Risk Management. Risk and its reduction or mitigation or prevision and prevention is increasingly becoming the central concern and this risk is present in pre impact and post impact contexts.

The UNISDR defines disaster risk management as "*the systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards.*"

A myriad of alternative if complimentary definitions also exist. As one illustrative example, the Central American Coordinating Centre for the Prevention of Natural Disasters (CEPREDENAC), the official Central American intergovernmental organization for disaster reduction and response, and the Andean Committee for Disaster Reduction (CAPRADE), two of the more long standing, experienced intergovernmental, regional organizations located in some of the most risk prone areas of the world, have defined disaster risk management as "*a social process that searches for the prevision and permanent control of disaster risk in manners that are consonant with and integrated into the planning of sustainable human, economic, environmental and territorial development. In* *principle this allows for different intervention levels from the global and integral, sectoral and macro-territorial through to local, communitarian and family based".*

Disaster risk management is seen by CEPREDENAC and CAPRADE to be a process and not simply a series of concatenated and related actions, whilst also considering the full range of activities and aspects associated with risk and disaster from prevention through to recovery and reconstruction. Risk is seen to be ever present in differing forms and dimensions.

Both definitions provide for a further delimitation of disaster risk management practice, distinguishing clearly between what is called corrective or compensatory disaster risk management where the interest is in reducing existing risk and risk factors, and prospective or proactive risk management where the interest is in avoiding new risk factors in the future through risk controls and considerations introduced in the development of new private and public sector projects and programs (see Lavell, 2005 for a thorough presentation and discussion of these concepts).

Disaster risk management clearly focuses on a general notion of "risk reduction" which has been defined by the ISDR as "*the conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of risks, within the broad context of sustainable development* (UNISDR 2002; also see Section 1.3.7).

Seen from the angle of the relations between disaster risk reduction and such other prevailing challenges as the need to reduce poverty and the need to adapt to climate change, the recent Global Assessment Review of the UNISDR (UNISDR, 2009) in its discussion of what it calls "risk drivers" has clearly established that the reduction of environmental services depletion, improvements in urban land use and territorial organization processes, the strengthening of rural livelihoods and overall and specific advances in governability are indispensable in order to achieve that triple agenda. They are strategies that cut across problems and serve to clearly link poverty reduction, adaptation and risk reduction strategies and instruments.

The concept of risk transfer has also gained increased interest and salience. Also described as "risk sharing" (see Section 1.4.), this approach refers to mechanisms that permit risk to be transferred to third parties or shared among a larger group. For instance, insurance policies ask for regular payment of premiums and in return will provide monetary compensation for losses if and when risks materialize. Insurance mechanisms may allow many of those affected by similar risks to pool resources that can then flow to those who suffer particular losses. In their direct form, such mechanisms offer financial protection but do not as such reduce the risk of primary loss and damage. However properly configured risk transfer mechanisms can encourage corrective and proactive risk management, for instance when insurance rates are calibrated to the level of existing risk—lower where action is taken to reduce primary risk and higher where such actions are not taken (see Lavell and Lavell, 2009, for examples of such uses amongst poor communities in the Bolivian uplands and the city of Manizales in Colombia). For instance, actions to reduce risk of flooding might include structural measures such as building levees and non-structural measures such as land use changes or restoring wetlands that can absorb flood waters (see Section 1.4.4).

The evolution of disaster policy and the goals of intervention in favor of increased concern for risk reduction and control as a necessary complement to disaster response and rehabilitation aspects has inevitably placed the previously existing institutional and organizational arrangements under scrutiny.

In many parts of the world -- whether it be with the Federal Emergency Management Authority- FEMA- in the USA or former disaster management organizations in Colombia, Nicaragua or Ecuador, South Africa, Mozambique or Angola, India, Bangladesh or the Philippines -- the increased importance given to risk reduction in a development framework has meant the need to search to diversify and increase the complexity of their institutional arrangements. The dominance of response-based organizations from government or civil society has been complemented with the increasing incorporation of sector and territorial development agencies, Ministries of Planning and Finance. Land use planning and environmental services agencies have now become indispensable components of more modern risk management systems. Systems as opposed to single agency approaches are now evolving all over the world. Synergy, collaboration, coordination, multidisciplinary and multiagency schemes are now seen to be required to guarantee risk reduction and risk management in a sustainable development framework **(CITE).** A classic case of institutional evolution can be found in the early Colombian evolution from a single civil defense type structure to the creation of its multi-institutional, multi-disciplinary, decentralized Disaster Prevention and Response System in 1989 after the impact of the Nevado de Ruiz eruption and lahar which killed 20,000 persons in Armero. This model served as an example in much of Latin America for years after and many countries built on it with their institutional transformations (Ramírez and Cardona, 1996).

The notions of hazard and risk, the latent danger associated with diverse non-routine physical events that range from extreme and rare to recurrent, and the potential for loss, are key to understanding disaster risk management. The level of the risk is determined both by the intensity and magnitude of the physical event as such and the differential levels of exposure and vulnerability of the diverse social and economic elements. The overall objective of disaster risk management is to limit the losses associated with such non-routine events in contexts where prevalent environmental norms and averages are the basis and fundamental factor in explainingongoing social productivity and economic gains and accumulation. This objective can be achieved by reducing the levels of exposure and social vulnerability to events, that is, all the factors that contribute to consequences in the probabilistic risk analysis framework. An understanding of, and the values people place on various potential consequences (see Section 1.3.5), along with expectations about the potential likelihood of the triggering events, can help inform decisions about the allocation of resources to reduce and manage the various risks a community faces. Positively managing such risks with a full portfolio of process and actions is what disaster risk management does and should help to do.

The management of non-routine events and the risk associated with them cannot be dealt with in isolation from the ongoing, normal context of every day life and the chronic or persistent social risk factors that typify it for many individuals (ill health, unemployment, lack of incomes, addiction and alcoholism, family and social violence, etc) (see Section 1.1). The idea that disaster and disaster risk are exceptional conditions counter-posed to normal life was convincingly debunked many years ago by amongst others Wisner et al (1976), Hewitt (1983), Blaikie et al (1994) and Wisner et al (2004). The only way of understanding disaster risk is to understand the ongoing social processes associated with every day life that lead to its existence and, on the other hand, the only way to be able to enact risk management principles is by framing and bedding these in a thorough understanding of the ongoing social demands of the population, particularly the poor who must deal with risk at all levels on a daily basis (Maskrey, 1987).

Managing the risk of extreme impacts includes managing the risk associated with non-extreme, but also non-routine events that affect the same areas on a more permanent and persistent basis, all within the framework of ongoing chronic risk, associated with poverty, lack of incomes, ill health, lack of hygiene etc. Managing extreme events and disasters is most usefully accomplished as one component of managing risk in general.

The concept of totality in dealing with risk is further developed on the understanding that the risks associated with climate variability and change can only be realistically dealt with if they are also considered in the light of other pervasive and permanent hazards associated with the natural and non natural environment—geological, geomorphologic, oceanic, technological etc. In other words, total integrated risk management requires holistic visions of environments, both human and natural. The lack of holistic visions will also be a cause of "mal-disaster risk management" and maldaptation as discussed in Section 1.4

1.3.4. Climate Change Adaptation Framework

Clmate change may change the disaster and other risks faced by communities. Climate change adaptation (see Section1.4) addresses actions taken to reduce and transfer such risks. In some cases climate changes may prove beneficial; climate change adaptation also aims to take advantage of such opportunities.

From their very beginning, human societies have faced and responded to climate variability and weather extremes Burroughs, 2005). But the literature on climate change adaptation dates largely from the mid- 1990s and is thus more recent than disaster risk management and its disaster management and emergency management predecessors. Working Group II of the Fourth IPCC Assessment Report defines adaptation as:

> *"The adjustment in natural or human systems in response to actual or expected climate stimuli or their effects,which moderates harm or exploits beneficial opportunities."*

The term climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity, so that climate change adaptation refers to responses taken in anticipation or response to changes of any mix of natural or anthropogenic origin.

Climate change adaptation rests on the key recognition that the risks to human and natural systems can vary as climate changes. Most germane to this report, climate change may affect the frequency and magnitude of extreme events in a region and the consequences of those events. In general, these systems face changes of two types: 1) chronic, gradual, long-term changes such as trends in climate averages, sea level rise, and shifts in ecosystems and 2) changes in the frequency and character of extremes of weather and climate such as droughts, floods, and storms. In any particular region, climate change may shift the frequency and character of extreme events, may contribute to changing conditions that can lead to extreme impacts and disasters as the physical and biological environment responds to non-extreme events,-or may introduce types of events and conditions new to that region but common elsewhere, such as forest fires or severe flooding in regions where such events were previously unknown. If global mean temperature rises high enough, some regions may begin to experience impacts outside the range of any previous human experience.

From its beginnings, the climate change adaptation literature has employed the concepts of vulnerability and adaptive capacity to capture the ways in which changing climate conditions can affect human and natural systems. These terms are also found in disaster risk management literature, though the exact definitions may differ (see Section 1.1.3.2 for controversies over these definitions).

The early climate change adaptation literature focused on identifying and characterizing vulnerabilities to various human and natural systems (IPCC ,1995). In recent years, however, communities worldwide have begun to take actions to reduce these vulnerabilities (see World Development Report 2010; IPCC 1990; US National Academy of Science 2010). Accordingly, the climate change adaptation literature has increasingly focused on the identification and evaluation of alternative options that can reduce vulnerability and increase adaptive capacity. In many cases, such actions are identical to those that might be considered by disaster risk management. For instance, a climate change adaptation analysis might suggest how a community can reduce vulnerability by moving populations away from regions that may in the future see more frequent floods, by improving its ability to monitor and evacuate when floods prove imminent, and by building and retrofitting buildings so they suffer less damage in floods. The community could increase its adaptive capacity by insuring against its economic losses, improving forms of social organization and collaboration, and improving its capability to rapidly repair and rebuild after any flooding.

Similarly to disaster risk managment, the climate change adaptation literature pays significant attention to the potential for *ex ante* action. Given its focus on the impacts resulting from temporal changes in climatic conditions, ideally climate change adaptationwill prove more effective the more it can anticipate future change. In some cases, *ex ante* actions may be necessary to an effective response. In other cases, it may prove less important. Irrespective of its importance, in some cases communities may be unable or unwilling to take *ex ante* actions and in other cases, as described in Section 1.4.4, attempts at anticipatory action may increase future risks. Accordingly, the IPCC distinguishes three types of adaptation to climate change that incorporate varying degrees of foresight (IPCC, 2001):

- *Anticipatory adaptation* – Adaptation that takes place before impacts of climate change are observed, also referred to as proactive adaptation. This is seen to be undertaken by persons and communities in the normal development of their lives as opposed to being incited by government intervention and plan.
- *Planned adaptation* – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.
- *Autonomous adaptation* – Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems and also referred to as spontaneous adaptation.

Other taxonomies have also been proposed. For instance, in a survey of 135 claimate change adaptation efforts in developing countries, The World Resources Institute describes “serendipidous adaptation” in which activities taken to enhance development objectives also decrease risks due to climate change, “climate proofing” in which ongoing development activities are augmented by actions to reduce risks due to climate change, and "discrete adaptation" in which actions are taken specifically to reduce risks due to climate change (McGray et. al. 2007).

In recent years the climate change adaptation literature has increasingly adopted an iterative risk management framework. This framework recognizes that the process of implementing the probabilistic risk analysis of Section 1.3.1 does not constitute a single set of judgments at some point in time, but rather an ongoing assessment, action, reassessment, and response that will continue – in the case of many climate-related decisions – for decades if not longer. The importance of such an iterative risk management framework is emphasized in the IPCC's Fourth Assessment Report, which states:

> *Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation, and takes into account climate change damages, co-benefits, sustainability, equity and attitudes to risk. (IPCC 2007).*

One exemplar process for implementing an iterative risk management climate change adaptation approach is shown in Figure 1-2. This 8-stage iterative process, developed by UK Climate Impacts Program (Willows and Connell 2003), is designed to help decisionmakers identify and manage their climate risks in the face of uncertainty and encourages users to consider climate risks alongside non-climate risks. While this approach provides a good example of the state of the art in the climate change adaptation literature, many communities have not adopted this or similar practices (as described below and elsewhere in this report).

[INSERT FIGURE 1-2 HERE
Figure 1-2: One example of an iterative risk management approach, developed and widely applied by the UK Climate Impacts Program (Willows and Connell 2003).]

1.3.4.1. Iterative Risk Management under Deep Uncertainty

As emphasized in several recent reports (NRC 2009; Morgan et. al. 2009) the uncertainties associated with many climate-related decisions present decision makers with conditions where the probability estimates are imprecise and/or the structure of the models that relate actions to consequences are often unknown. Such deep or severe uncertainty (see Lempert and Collins 2007 for a discusion of various terms used in the literature for this type of uncertainty) can characterize not only understanding of future climatic events but also future patterns of human vulnerability and the capability to respond to such events.With complex, poorly understood physical and socio-economic systems like many of those involved in climate-related decisions, research may enrich our understanding over time, but the amount of uncertainty, as measured by our ability to make specific, accurate predictions, may grow larger. In addition, theory and models may change in ways that make them less, rather than more reliable as predictive tools over time (Oppenheimer et al 2008). For instance, governments at the December 2009 climate negotiations in Copenhagen set a goal of preventing temperatures from rising beyond 2°C above preindustrial levels. Climate science research may reveal previously unanticipated impacts if global mean temperature increases grow beyond this target, thus increasing the range of potential risks.

Overcoming these challenges require augmenting the basic iterative risk management framework in two important ways (NRC 2009, Morgan et. al 2009):

1) Recognize and manage the deep uncertainties facing many climate related decisions.
2) Embed iterative risk management in a broader process of institutional learning and adaptive governance in a manner which captures the full range of knowledge available including from local, indigenous experiences and other sources, and corresponding variations in experience and perception of risk from group to group (see Section 1.3.5).

In response to such deep uncertainties, many climate-related decisions should seek to be robust, that is, to perform well compared to the alternatives across a wide range of plausible future scenarios, even if they do not perform optimally for any particular scenario. The iterative risk management framework can implement this concept by characterizing probabilities by a range of plausible values or by a set of plausible probability distributions (Morgan et. al., 2009). Although many risk assessment tools provide optimal strategies, such strategies may prove brittle if the probabilistic expectations on which they are based are sufficiently imprecise (Lempert and Collins 2007). They may also prove overly contentious if different stakeholders have sufficiently different expectations about the future. Robust uncertainty management strategies may address some of these difficulties by performing adequately and enabling multiple decision makers to agree on a portfolio of actions, even if they disagree about values and expectations (see Section 1.3.5). Example applications of such ideas are beginning to appear in the climate change adaptation literature (Means et. al. , WDR 2010; Brown and Lall 2006, Dessai and Hulme 2006).

An iterative risk management framework also emphasizes the importance of learning and adaptive strategies, those explicitly designed to evolve over time in response to new information (Morgan et. al. 2009: NRC 2009). The learning theme has also been a long-standing focus in the literature on resilience. For instance, adaptive management, an important theme in environmental management, rests on the notion that policy interventions should be viewed as experiments and learning opportunities. That is, adaptive management addresses uncertainty about the future environment and human systems by consistently testing, monitoring, and revising policy assumptions. Well-conceived interventions designed to both improve conditions and provide information about the efficacy of various policy interventions, combined with systematic monitoring to track outcomes can in principle significantly improve responses over time. However, adaptive management has had a mixed history of implementation because organizations often find it difficult to design actual interventions as experiments, to spend resources on monitoring, and to document failures sufficiently well to facilitate learning. Nonetheless, recent literature has also seen an emphasis on what is called adaptive governance (Olsson et. al. 2006; Scholtz and Stiffel 2005). This approach suggests that a key uncertainty is often the efficacy of alternative institutional arrangements and design, and thus extends adaptive learning approach to the design and modification of institutions. The particular challenges relevant to applying such frameworks to the vast range of conditions in least developed countries is discussed in Section 1.3.6.

The climate change adaptation literature recognizes that many barriers exist to effective adaptation. These include the difficulty in recognizing gradual changes and changes in the frequency and character of rare events, and understanding and turning them into actionable information. Many societies also have trouble expending near-term resources to address longer-term issues, even when those actions are clearly cost effective in the long-term. Some societies lack the resources to address any but their most immediate needs. Richer societies often face political or cognitive barriers for such investments **(CITE)**.

1.3.5. Integrating Disaster Risk Management and Climate Change Adaptation

Disaster risk management has evolved over the last decades under the stimulus of changing concepts, circumstances, approaches and social and economic demands. The complementary nature of reactive disaster response and proactive risk reduction and prevision stances, including the move from reactive mitigation to proactive risk prevention, is but one of these, and is increasingly prevalent, if not as yet mainstream, at the practical level. Climate change will pose a new challenge and lead to new changes, driven by the key concepts of non-stationarity, that is, the realization that past experiences may no longer be a reliable predictor of the future character and frequency of events and of the responses of human systems to these. A further useful concept is complexity, including the changing interrelationships between factors, scales and territories.

Non-stationarity and complexity can affect disaster risk management in several ways:

- Climate change will directly affect the frequency and character of extreme events. What had previously been considered a five hundred year event may become a hundred, fifty, or even a thousand year event. Events may occur with no analogue in the historical record, such as wildfires in areas previously too wet to burn or extended drought combined with extreme temperatures.
- The effects of climate change on physical, biological, and other systems may affect patterns of exposure and vulnerability, changing the relationship between extreme *events* and extreme *impacts*. For instance, rising sea levels may affect the vulnerability of coastal communities to storm surges. Changes in agriculture may induce migrations that affect the vulnerability of both the places that lose and gain new populations.
- Attempts to adapt to climate change may also affect patterns of exposure and vulnerability. For instance, communities might make changes in water and agricultural systems in anticipation of climate change and

unknowingly create new vulnerabilities in those systems. This dynamic is not new. Commentators have described the "levee effect" in actions designed to reduce certain risks can create other, even larger, risks **(CITE)**. Climate change may increase the potential for such mal-adaptation, including displacement of risk from one location or time or population to another (see Section 1.4.4.1).

Based on this assessment, we conclude that the major foreseeable topics that will demand new or modified approaches and responses from the disaster risk management community are:

- The need to deal with greater levels of uncertainty as to magnitude, intensity and return periods of potentially damaging events, ranging from extreme to typical.
- The need to consider the changing relationships between consequences of events with a range of characteristics. Climate change may affect differentially the occurrence of small, medium, large scale and extreme events and their balance in any one area or region. These changing relationships will be critical in the design of disaster risk management and development strategies in general and fundamental for considering the adaptation problematic. Changes in the relationships among non-routine events merit particular attention.
- The need to consider both non-routine extreme and more routine climate events and their impacts in the framework of changing climate averages and norms and their effects. Unlike conditions under historical stationary or stable climate where climate averages or typical weather has not been a source of stress but rather the basis of development in many zones and regions, the future new and even unpredictable averages of temperature, rainfall, humidity etc will in some circumstances be themselves a source of additional tension and stress and the basis of potential new disaster. This will increase the importance of learning and of adopting more holistic processes as regards development and disaster risk management and the integration of concerns for averages and extremes in a single planning framework from the beginning (see Lavell, 2009).
- While areas historically affected by extreme and non routine events will continue to be affected in different proportions and measures, new areas will suffer unfamiliar processes and events for which they are not accustomed (and some may suffer fewer). This will require new processes and procedures. Distinguishing between anomalous, extraordinary and potentially recurring events will be extremely difficult over short and medium time periods.
- Climate change will simultaneously localize and globalize effective disaster risk management. The climate adaptation literature emphasizes that adaptation decisions are fundamentally place-based. However, climate change may create correlations among increasing risks that affect resiliency and risk sharing regionally and globally. For instance, all coastal areas globally evcentually will be affected by sea level rise. An entire region may experience a change in the frequency of storms, which may stress the resiliency of regional disaster response and the solvency of any insurance mechanisms. In addition, climate change may introduce human agency into changing hazards that were previously viewed as arising solely from acts of god or nature. Any future ability, for instance, to attribute an increased frequency of severe storms to increased concentrations of greenhouse gases may affect views about the responsibility some nations bear for disasters that strike other nations (Allen, 2003).

1.3.6. How These Frameworks are Implemented in Practice

The agendas of policy-makers and practitioners working on climate change adaptation and disaster risk reduction have converged in recent years, and it has been recognized that the capacity to manage extreme events more effectively is an essential aspect of adaptation to a more volatile and unpredictable climate. The Hyogo Framework for Action 2005-2015 under the United Nation's International Strategy for Disaster Reduction (UNISDR) promotes the integration of disaster risk reduction associated with today's climate variability and future climate change into national strategies, and includes risk identification, design of risk reduction measures and an operational use of climate risk information by planners, engineers and other decision-makers (Pilot Program Year?). In developing countries, the Global Facility for Disaster Risk Reduction – a partnership of The World Bank and UNISDR - supports the integration of disaster risk reduction through country risk assessments and capacity building, policy advice and strategy formulation, and rapid technical and financial response and recovery in post-disaster situations. Similarly, climate change adaptation and disaster risk management have become a strategic priority for multi-lateral development banks, bi-lateral development agencies and non-government organizations, and programs to increase climate resilience are being pilot tested in a number of vulnerable developing countries (NRC 2006) Also, many development agencies have started to systematically screen their investment portfolio for climate risk, and consider climate risk and vulnerabilities in project identification and design. But also rich countries are changing their risk management practices in light of recent extreme events that revealed short-comings in preparedness and response (as the 2002 floods in Germany, the 2003 heat wave in France, or Hurricane Katrina in 2005 in the USA), and are making efforts in improving geo-spatial risk information, early warning and communication system, public awareness, and the understanding of the human dimension of disasters (Birch, Wachter 2006).

1.3.6.1. Good Practices

Understanding risk is essential to promote action and requires investment in scientific, technical, and institutional capacity to observe, record, research, analyze, forecast, model, and map natural hazards and vulnerabilities. While rich countries generally have systems to routinely collect and analyze information pertaining to risk and provide such information as a public good (e.g. flood zoning program, land tenure records), many low- and middle-income countries have only recently started to build their capacity to perform basic (i.e. generally low-cost, ad hoc and simple) risk assessments, improve risk management practices (e.g. through better inter-agency coordination), and put policy frameworks in place to reduce disaster risk. But ubiquity of information and high capacity to model and analyze risk does not necessarily result in systematic risk reduction, as in the case of New Orleans where many of the same fundamental risk patterns continue to prevail after the destructive hurricane Katrina (FEWS).

Still, an important activity is the development of capacity to systematically collect and disseminate information pertaining to risk and vulnerabilities, e.g. to map key physical assets, household characteristics and physical hazards. Good practice can involve both high-tech and low-tech solution, such as the mapping of high risk areas (e.g. coinciding high population density and physical hazards) by integrating satellite remote sensing data of urban structure with ground-based, geo-referenced surveys (see Box 1-4). For instance, the Central American Probabilistic Risk Assessment uses state-of-the-art observation systems, geo-spatial modeling and risk analysis to improve the understanding of disaster risk in the region, and uses web-based communication to provide decision support to local decision-makers. But equally important are low-tech actions at the community-level in low-capacity environments such as systems of basic indicators that monitor *inter alia* seasonal weather characteristics, food prices and grain reserves to track poor rural communities' propensity to suffer from seasonal droughts (ECLAC 2003). Having a clear framework to methodically estimate post-disaster losses and assess sector impacts using empirical techniques is an important step to improve the knowledge base about key risks and vulnerabilities, in particular in poor countries that have little and often unreliable statistical information on disasters (the methodology for estimating the socio-economic an environmental effects of disasters originally developed by the Economic Commission for Latin American and the Caribbean is now widely used and adapted internationally; Hoeppe and Gurenko 2006).

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Box 1-4. Spatial Modeling

Spatial modeling provides an important tool for disaster risk management. Spatial risk modeling approaches can facilitate the development of disaster risk management action plans by helping to identify the level of disaster risk in different locations and to prioritize areas for disaster risk prevention, preparedness, reduction or mitigation. Spatial modeling can assess potential damages from disasters, locate potentially damaged infrastructure and emergency shelters, and design evacuation routes for emergency, to name a few. Spatial modeling can also effectively display changes in vulnerability to disaster over a specific area and time. Therefore, it can be effectively used for raising awareness. It can incorporate diverse thematic maps such as land use maps or topological maps with data regarding social, natural, and economic aspects, and consequently provide a comprehensive understanding of disasters.

Such spatial analysis reveals that the spatial and temporal pattern of vulnerability to disaster in the US during the past four decades,1960-2000, has changed (Cutter and Finch, 2008). A study on flood vulnerable areas of North Korea identified prioritized areas for disaster risk reduction (Myeong et al, 2008). A climate change vulnerability assessment of Southeast Asia (Arief and Francisco, 2009) provided information on areas most vulnerable to climate change, using maps of hazard, sensitivity, and adaptive capacity. With the spatial model of risk vulnerable areas shown in each of these case studies, it is possible to identify areas most vulnerable to a certain type of extreme events including those whose risk may increase due to climate change. Such a model would be useful to decision makers involved in setting development goals or targets.

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Also, many countries have taken legislative and institutional reform measure to address the joint challenge of adaptation and disaster management. In the Philippines, one of the most disaster-prone countries, the recently created Presidential Climate Change Commission coordinates climate policy across different sectors and in Mozambique, the government has strengthened its institutional coordination, communication systems and support to local communities after the devastating floods in 2000. Further, a key aspect of effective disaster risk mitigation is the active inclusion of local governments and a national risk management framework supportive of local action. Local government plays a key role in coordinating and sustaining a stakeholder process, engaging local citizens and communities in risk reduction, pilot-testing innovative tools for disaster risk, management of infrastructure, and the design and execution of development plans. Respectively, national risk management strategies need to be informed by practices and knowledge at the local level.

Poor countries are increasingly using risk management instruments to prepare themselves financially for extreme events and to be able to respond rapidly and effectively after disasters (World Bank, 2008) as the 16 Caribbean countries that pool their resources in a contingency fund to provide liquidity to maintain essential government services in the immediate aftermath of extreme hurricane or earthquake events reveal (Mahul amd Stutley 2010) Similarly, after several years of pilot-testing farmers in India now can purchase weather-index insurance, a simplified form of insurance based on observations, that provides rapid compensation during seasonal droughts. In both (and in many other similar) cases the private sector is an important partner to spread and diversify catastrophic risk domestically and internationally. These innovative projects provide important lessons for developing countries to access financial markets to more effectively manage disasters risk and develop their own insurance markets using simplified products that are adapted to a situation characterized by small and often poor households in the developing world, and a nascent private sector for financial services.

It is important to note, that while risk financing (insurance) has emerged as important climate risk management tool, it can only be effective and sustainable as part of a broader risk management framework that promotes systematic risk reduction and preparedness. An important concept is the layering of risk, whereby communities and households make arrangement to buffer against smaller losses, the private sector provides insurance products for insurable (i.e. not too frequent) losses, and the government makes provisions to prepare for catastrophic losses that exceed the capacity of households or private insurers (Mahul and Skees 2007). Such concepts of risk layers have for instance been put in practice in Mongolia to protect herders against livestock losses due extreme cold episodes(Convenient Solutions year?).

Management of natural systems is fundamentally important to risk management (World Resources Institute 2008) Coastal mangrove forests protect against storm surges partly by absorbing the flows and partly by keeping human settlements behind the mangroves farther from the sea. Similarly, forested catchments buffer water flows from moderate rains far better than non-forested catchments. Vegetated wetlands buffer water flows, but wetlands converted to agriculture or urban settlements and simplified drainage systems inevitably fail, resulting in flooding. Thus, a comprehensive response to flood management includes maintaining ecosystems services by managing vegetation cover in the catchment areas, managing wetlands and river channels, and siting infrastructure and planning urban expansion appropriately. Similarly, carefully managed production landscapes increase water storage and soil fertility and increase resilience to protracted periods of drought (World Bank 2009).

1.3.6.2. Issues Particular to Developing Countries

Developing countries are expected to experience the effects of climate change most severely (World Bank 2008) Most of the human losses (in absolute terms) and economic losses (in relative terms) due to extreme events are borne by developing countries today. Improving the management of extreme events and extreme impacts is often complicated by the lack of reliable and timely information on disaster risk, whilst the acute combination of increasing exposure and vulnerability associated in many instances with poverty increases enormously the complexities of risk reduction and risk prevention strategies and instruments.

Sparse and dated observations systems hamper the operation of risk monitoring, early warning, and post-disaster loss assessments. Many national hydro-meteorological services struggle to maintain a basic network of observational infrastructure as well as to develop services that translate basic data into information useful for decision-makers and planners (IRICS, 2006; Balk et al, 2008).

The synergic relations between disaster risk, poverty, mismanagement of natural resources, lack of land use planning, severe problems of governance in many countries and the challenge of climate change adaptation requires integral internvention schemes that belie the options and are compounded by the sectorialised views and actions of many government and international agencies (see ISDR, 2009 for a detailed revision and consideration of these aspects). The combination of encroachment in hazardous zones due to urban development (Balk, D.G, McGranahan and B. Anderson) lack of enforcement of building codes, and degradation of natural systems contribute to a relatively high degree of physical vulnerability in the developing world. The lack of service provision – access to financial services, water, education, communication – further amplifies the vulnerabilities of the poorest segments of society in particular.

Governments bear an implicit liability in relation to disasters and historically have acted as ‘insurer of last resort’ (Kunreuther and Michel-Kerjan, Linnerooth-Bayer and Mechler2006). Yet, many small economies have little capacity to absorb disaster losses (e.g. Grenada lost 200% of its GDP during hurricane Ivan), and even donor contributions generally fall short of covering the extent of disaster losses (OECS 2004; Melcher 2009). A challenge thus is to provide rapid and targeted financing to allow governments to re-establish government services and rebuild critical infrastructure to avoid longer-term economic losses. Similarly, insurance markets in developing countries are relatively thin and as of today provide little risk protection for households and businesses through the private sector.

1.4. Coping and Adapting

Coping and adapting are significant terms for disaster risk management and climate change adaptation in both scholarship and practice. From a historical perspective, coping came into favor in development work in the 1960s – at times closely associated with the notion of survival strategies amongst the poor and later, in the 70s, in response to famine conditions in Africa (**CITE- PELLING**)– and was taken up bydisaster risk management specialists from the ‘90s onwards in particular. In the first decade of the 21st century, for instance, the ISDR stated that disaster occurs in part because a community’s ability to cope has been exceeded. The disaster risk management community is currently divided, however, on the role of coping in both theory and practice.

Adaptation, in turn, has been a central term for the climate change adaptation community since the IPCC’s First Assessment Report (FAR) in 1990, and has been progressively incorporated into disaster risk management frameworks and terminology since the FAR was published. In recent years the climate change adaptation community, alongside their disaster risk management colleagues, has taken up the discussion of how coping and adaptation relate. Even more recently, both camps have struggled to integrate these terms with the notions of resilience and maladaptation in efforts to advance climate change adaptation theory and practice.

While the terms are used frequently, their meanings have not been rigorously discussed since Davies in 1993 (Davies 1993) and there is great “conceptual confusion” surrounding the two terms (Davies 1996). The terms are often co-mingled or used interchangeably such that their meanings are confused, and until recently there have been no definitive reviews of their relationship. In the last decade there have been some gestures toward a unifying approach in which coping experience can be seen as a means of strengthening, promoting, or advancing climate change adaptation, as attempted by a United Nations Framework Convention for Climate Change- UNFCCC- Delhi workshop in 2003 (UNFCCC 2003) and a more recent reflection on the terms and the utility of the two strategies (Schipper, et al. 2010). These efforts have uncovered both friction and synergy, however, and the issues remain unresolved. The debate is not merely semantic, as the conceptions of coping and adaptation have implications for programming and funding. Emphasis on coping, for instance, tends to cast efforts in terms of recovery and integration of loss, while emphasis on adaptation focuses on transformation.

The present discussion has two goals. First, it is an attempt to assess the definitions of these notions and discern between differing views by examining usage across time and disciplines. This explication is in service of distinguishing the two terms, identifying acceptable common ground, and identifying any mutually reinforcing relationships. Ultimately, it seems that a key distinction is whether a process is pre- or post-impact: both coping and resilience are primarily post-impact notions that reinforce recovery from a disaster, if incompletely. Adaptation is primarily pre-impact, anticipatory, and potentially transformative. Both are necessary to facilitate climate change adaptation, but as the hazard landscape is increasingly dynamic, and many extreme impacts are becoming more severe and less reliably predictable (see Chapter 3), adaptation is likely to be increasingly important. The process is fraught with pitfalls, however, that can result in maladaptation. This leads to the second goal of this section: to assess the notion of maladaptation and to reframe the notions of coping and adaptation as approaches to learning from experience. This vantage point deemphasizes the tension between coping and adapting and reframes the issue as one of maximizing learning, both to facilitate recovery in the short term and to promote appropriate transformations over longer time horizons.

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Box 1-5. Adaptation to Rising Levels of Risk

Before 1000 CE, in the low lying coastal floodplain of the southern North Sea and around the Rhine delta, the inhabitants lived on dwelling mounds, piled up to lie above the height of the majority of extreme storm surges. By the 10th Century, as the population of what is now the Netherlands rose to an estimated 300,000 people, the first dykes had begun to be constructed and within 400 years ringed all significant areas of land above spring tide, allowing animals to graze and people to live in the protected wetlands. The expansion of habitable land encouraged a significant increase in the population exposed to catastrophic floods (Borger and Ligtendag 1998). The weak sea dykes broke in a series of major storm surge floods through the 13th and 14th Centuries (in particular in 1212, 1219, 1287, and 1362), flooding enormous areas (often permanently) and causing more than 200,000 fatalities, reflecting an estimated lifetime mortality rate from flood for those living in the region in excess of 5% (assuming a 30 year average lifetime; Gottschalk, 1971, 1975, 1977).

Major improvements in the technology of dyke construction and drainage engineering began in the 15th Century. As the country became richer and population increased (to an estimated 950,000 by 1500 and 1.9 million by 1700), so it became an imperative not only to provide better levels of protection but also to reclaim land from the sea and from the encroaching lakes, both to reduce flood risk and expand the land available for food production (Hoeksma, 2006). Examples of the technological innovations included: the development of windmills for pumping, and methods to lift water at least 4m whether by running windmills in series or through the use of the wind-powered Archimedes screw. As important was the availability of capital to be invested in joint stock companies with the sole purpose of land reclamation. In 1607 a company was formed to reclaim the 72km^2 Beemster Lake north of Amsterdam (twelve times larger than any previous reclamation). A 50km canal and dyke ring were excavated, a total of 50 windmills installed which after five years pumped dry the Beemster polder, 3-4m below surrounding countryside, and which, within 30 years, had been settled by 200 farmhouses and 2000 people. Since the major investment in raising and strengthening flood defenses in the 17th Century, there was only one major flood in 1717 (when 14,000 people drowned), since which time the total flood mortality has been around 1000 per century, (with two notable floods in 1825 and 1953), equivalent to a lifetime mortality rate (assuming a 50 year average lifetime) of around 0.01%. , 500 times lower than that which had prevailed through the Middle Ages (Van Baars and Van Kempen 2009). This change is considered a result of increased protection rather than any reduction in storminess. Since 1953 the flood risk has been reduced at least an equivalent step further.

_____ END BOX 1-5 HERE _____

1.4.1. Denotations and Connotations

While this section is concerned with coping and adapting in the contexts of disaster risk management and climate change adaptation, it is helpful first to look at the terms' dictionary definitions, from which the disciplinary meanings derive. The *Oxford English Dictionary* defines *coping* as "The action or process of overcoming a problem or difficulty . . . or . . . managing or enduring a stressful situation, condition" and *adapting* as "rendering suitable, modifying" (OED 1989). Contrasting the two terms highlights several important differences that are evident in their dictionary and even common usage definitions, examples of which can be found in the literature cited:

- The first is exigency: coping implies survival in the face of immediate, unusually significant stress, when resources, which may have been minimal to start, are taxed (Wisner, Blaikie et al. 2004), whereas adapting suggests reorientation in response to change, often without specific reference to resource limitations.
- The second is entrenchment: in coping, survival is foremost and bounded by available knowledge, experience, and assets, and reinvention is a secondary concern (Bankoff 2004), while in adapting, creative flexibility is a necessity.
- The third is reactivity: coping is tactical, managerial, and used to protect basic welfare or survive when after an event has occurred (Adger 2000), while adapting is strategic, transformative, and focused on anticipating a situation or changing pattern and addressing the anticipated change proactively (Fussel 2007).
- The fourth is orientation: coping is focused on past events that shape current conditions and, by extension, on previously successful tactics (Bankoff 2004), while adapting is oriented toward future possibilities and incorporates past tactics to the extent that they facilitate adaptation to changing future conditions, though according to some the two can overlap and blend (Chen 1991).

Overall, in coping the focus is on the moment, constraint, and survival; in adapting, the future is the focus, learning and reinvention are key, and survival is less in question.

These common meanings have implications for the themes discussed in the remainder of this section. Principally, coping emphasizes survival or getting by post-event, "surviving but not thriving", and is by default more oriented toward the status quo. Schipper et al. point out that coping's goal is in fact to return to normal, if not necessarily optimal, function (Schipper et al. 2010). Adaptation, in contrast, is closer to the notion of development. Coping has been used in the disaster-related literature for decades and its meaning has changed over time, but it was originally developed and used when the field's focus was on reactive, response based *disaster or emergency management* (CITE). Since then, the disaster theme has evolved to focus much more on integral *disaster risk management* (see Section 1.1) and become more development oriented and adaptation focused (CITE). However, coping and related terms are still used in the disaster risk managment literature and have been integrated into the climate change adaptation literature as well, leading to a significant interpretation problem that is the subject of the next several subsections.

One possible hypothesis then regarding the current uses of the term coping is that its use has not kept pace with this evolution in disaster risk management, i.e. that there has been gradual drift from the word's original use and meaning as disaster risk management has moved ever further toward a holistic, proactive, transformative approach. This definitional drift now muddles the role and potential utility of coping strategies in the larger climate change adaptation effort, which is also focused on proactive interventions. Box 1-6 traces the evolution of coping, adaptation, and related terms and recasts their meaning in light of the current state of the disaster risk management and climate change adaptation fields to provide explication of their changing meaning over time as background to the current state of affairs discussed in the next section.

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Box 1-6. Coping Historically

General trends in usage of the term coping can be teased out, though there has been significant controversy among disaster risk management and climate change adaptation theorists and practitioners regarding coping's role. Following is a review of the evolution of the term coping in the specialist literature.

Origins in the Disaster Risk Management Literature

The dictionary definitions of coping and adapting are in play in the disaster risk management literature but there are some important definitional nuances. These evolved over time in response to two changes in the field. The first was the need to make disaster risk managment more bottom-up by including local and indigenous practices: "the application of indigenous knowledge in the face of hazards and other threats is referred to as 'coping mechanism' or 'coping strategy' . . . (and in some circumstances as a 'survival strategy')" (Twigg 2004). Twigg also noted the potential for coping to serve as a point of entry rather than an end unto itself. In this he highlighted the association between disasters and development first systematically discussed by Cuny in 1983 (Cuny 1983).

The second trend in disaster risk management that influenced the evolution of the term coping was its progressive reorientation toward proactive risk management with emphasis on disaster risk reduction as sustainable development (broadly construed to include socio-cultural development, political stability, economic growth, land use planning and ecosystem protections). Development and disaster risk management began their more formal integration in the late '80s when coping and adjustment mechanisms (technological, social, organizational, and cultural) were first discussed in 1992 (Clarke Guarnizo 1992). In this line of disciplinary discussion, the term coping became more elastic in comparison with dictionary definitions, particularly regarding orientation and reactivity. Specifically, coping's relation to a hazardous event was expanded to include both processes occurring *ex post* a hazardous event as well as in anticipation or *ex ante* during periods of relative normalcy, perhaps in order to retain its utility as a way to emphasize bottom up practice while also allowing for more of a development orientation.

These trends have prompted the question of where coping strategies sit in the disaster risk management cycle. As disaster risk managment has evolved, some practitioners have preferred to equate coping with the response phase (see Figure 1-3), while others have preferred to integrate the term into other phases to emphasize the importance of indigenous practices (UNISDR 2008; UNISDR 2008; UNISDR 2009).

[INSERT FIGURE 1-3 HERE
Figure 1-3: ______________________ (Keim, 2008).]

At the same time, others in the disaster risk management community criticized the use of coping capacity as a strategy. In particular, practitioners in the global South felt that coping, with its connotative emphasis on survival and on getting by, did not place enough emphasis on addressing structural problems and thereby avoiding the need to cope in the future (Davies 1993). The common theme between these schools, it would seem, is the need for a framework that allows for proactive, anticipatory action while recognizing the value of indigenous knowledge and practice where applicable, but also highlighting the importance of learning and deliberately transforming in response to changing conditions.

Coping in Early Climate Change Adaptation Literature

The climate change adaptation community inherited the confusion and tension associated with coping when it began to use the term (and the related "coping capacity") in its literature. For instance, Adger explored the possibility that migration could be considered either coping or adaptation (Adger 2000). Efforts to merge the terms from disaster risk management and climate change adaptation were rare, however, until a 2003 conference on coping and climate change adaptation sponsored by the UNFCCC where the topic was discussed explicitly. While not primarily a scholarly meeting, this conference was a noteworthy attempt to bring together different lines of theory and practice. Echoing disaster risk management's interest in building on local expertise, the conference participants emphasized the value of "local knowledge" that "embodies a wide variety of skills . . . closely linked to community survival and subsistence . . . blending many knowledge streams to solve local problems", and highlighted successful coping strategies including indigenous forecasting and early warning systems, flood and drought management, mutual support, livelihood switching, and evacuation and migration (UNFCCC 2003). Participants noted the limits of coping, as well, and the difference between "thriving versus surviving."

Participants also highlighted an important consequence of coping strategies, i.e. that coping as an ex-post activity often promotes deep debt and thus exacerbates vulnerability. This echoes others' work on the topic (Risbey, Kandlikar et al. 1999). They also distinguished coping from recovery whereby external resources are introduced to facilitate return to pre-disaster function, emphasizing that coping is only part of a larger risk management strategy. Finally, they noted pitfalls of relying on coping strategies to deal with climate change, as the lack of stationarity (Milly, Betancourt et al. 2008) may result in some events falling outside the "historical coping range." They recommended that the climate change adaptation field examine coping strategies for similarities across contexts (UNFCCC 2009) and further research on coping strategies with an emphasis on risk communication and evaluation. Ultimately, however, the participants concluded by emphasizing that development should serve as the primary climate change adaptation strategy: "Perhaps what should be done is to look at local communities that are facing climate-related risks, then address their development needs while incorporating climate change concerns into these interventions … This approach provides greater sustainability because it uses existing structures and community concerns" (UNFCCC 2003).

_____ END BOX 1-6 HERE _____

[INSERT FIGURE 1-4 HERE
Figure 1-4: Evolution of climate change adaptation and disaster risk management.]

1.4.2. Coping as Currently Construed

In more recent literature the terms coping, coping capacity, and coping range have been used in various ways. Comparing and contrasting recent usage in light of the dimensions noted above (exigency, entrenchment, reactivity, and past orientation) helps highlight continuing themes as well as substantial differences in the way the terms continue to be employed.

1.4.2.1. Recent Disaster Risk Management Literature

As noted above, there is ongoing debate in the disaster risk management community regarding the strategic value of coping. Nevertheless, the term and its variants continue to figure prominently in recent publications such as the 2008 ISDR *Indigenous Knowledge for Disaster Risk Reduction*, where coping mechanisms and strategies are prominent and divided into three categories: social (including institutions and other forms of social capital), functional (including building and land use practices), and sequential (including strategies to protect livelihoods such as dietary changes and migration) (UNISDR 2008). The ISDR emphasizes the importance of coping mechanisms as part of priority 3 of the Hyogo Framework for Action focusing on education and knowledge (UNISDR 2005), but acknowledges that coping mechanisms are primarily entertained under periods of significant stress and that effective disaster risk management also includes a strong emphasis on development (UNISDR 2008). Even in disaster risk management publications focused on development, however, coping mechanisms figure prominently and are framed in a relatively positive light, and poverty or lack of development are seen as undermining coping capacity.

Coping, per se, is not defined in the IPCC, UNFCCC, or ISDR glossaries, but the ISDR does define coping capacity. It's most recent (2009) glossary definition is:

> *The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters. The capacity to cope requires continuing awareness, resources*

and good management, both in normal times as well as during crises or adverse conditions. Coping capacities contribute to the reduction of disaster risks.

Compared with earlier ISDR definitions of coping capacity, the 2009 definition places more explicit emphasis on management. It seems to situate coping as a post-event process, but also acknowledges the importance of "continuing awareness" during 'normal times as well as . . . crisis", suggesting that coping is an ongoing risk reduction strategy. These aspects of the definition help establish a bridge between coping and accepted processes of climate change adaptation and disaster risk management, including land use planning and livelihood security schemes, and harmonize the definition with current development practice focused on longer term adjustment, adaptation or risk reduction and control goals. Similar trends are apparent in definitions from other organizations, glossaries, and journal articles discussing the overlap between disaster risk managment and climate change adaptation(Schipper, Pelling et al. 2006; Thomalla, Downing et al. 2006; van Aalst 2006; see also Section 1.1.3.4 for the related discussion of the integrated view of the extreme and the every-day experiences).

1.4.2.2. Recent Climate Change Adaptation Literature

While coping has been peppered throughout climate change adaptation literature since the FAR through the AR4, the term is not nearly as prominent as adaptation. For instance, in AR4 Chapter 17 on adaptation mechanisms and processes, coping is only briefly referred to twice in the written text and a very limited number of times in the quoted references. In more recent papers on climate change adaptation, coping appears somewhat more frequently, but more commonly coping capacity and related terms such as coping range are used, and then almost always in conjunction with adaptive capacity. Kelly and Adger examined the terms in a 2000 paper on vulnerability and adaptation (Kelly and Adger 2000) and Saldana-Zorrilla recently offered explicit definitions (referring to Kelly and Adger's work), defining coping capacity as "the ability of a unit to respond to an occurrence of harm and to avoid its potential negative effects," and adaptive capacity as "the ability of a unit to gradually transform its structure, functioning or organization to survive under hazards threatening its existence" (Saldana-Zorilla 2008). Here the meanings of the two terms are closer to their common meanings, though the dimension of exigency has been extended to adaptation as well as coping, underlining the severity of the climate change threat.

In a recent contribution, Schipper et al. parse the meanings of both coping and adapting, concluding that the central distinction between coping and adaptation is that "coping actions do not imply any adjustment to new conditions" and that "coping strategies are more about avoiding facing risk or change than about adjusting to its presence" (Schipper et al.2010). They conclude that coping strategies may have a place in longer term adaptation efforts, primarily to ensure survival by "helping avoid that a hazard turns into a disaster." To help clarify the difference between coping and adapting, they propose an analytical tool composed of a series of questions related to the intervention. The parameters of their tool roughly parallel the dimensions discussed at the beginning of this section (exigency, entrenchment, reactivity, and orientation), focusing on whether the intervention is primarily short term, resource intensive, a part of normal activities, and whether it is abandoned when normal activities resume. The tool also assesses the degree to which the intervention reduces the exposure to a hazard or a population's sensitivity to it, whether the intervention has worked well in the past, and whether it is focused on improving well-being in the long term (Schipper et al. 2010). Overall, their piece is a significant step toward systematic, methodical distinction between the two terms, though their approach is primarily descriptive and does not resolve the question of how the notion of coping should be used in disaster risk management and claimate change activities.

Despite increasing clarity regarding the term coping, dangling threads remain, particularly in relation to certain related terms that have acquired their own disciplinary meanings in recent years, such as the term "coping range." Neither the UNFCCC, the IPCC, nor the ISDR has defined the term explicitly, though by inference in the 2003 UNFCCC conference proceedings, coping range appears to have been defined as the historical context within which a particular coping mechanism had been effective at maintaining essential functions during periods of severe stress. Others, particularly Yohe and Tol, have a different perspective. They assert that coping range is "a range of circumstances within which, by virtue of the underlying resilience of the system, significant consequences [of change and variability in a system] are not observed"; they also characterize the coping range by its boundaries, i.e. the "thresholds beyond which the consequences of experienced conditions become significant" (Yohe and Tol

2002). Importantly, they deemphasize both entrenchment and past orientation by asserting that coping ranges are not static and can shift over time. They develop a formula through which adaptation supports coping capacity, maintains or extends coping range, and thus enables maintenance of a system's essential function (resilience). In this framework there is no discussion of thriving versus surviving and the dimensions of exigency and entrenchment appear to have been minimized if not eliminated entirely. Moreover, differently than others' aproaches, for Yohe and Tol adaptation supports coping and thereby "advances" disaster risk management strategies.

Yohe and Tol's definition of coping range refers to resilience, as do the ISDR definitions cited above. Effort to parse the definitions further quickly becomes cyclical, however, as the following ISDR definition of resilience illustrates:

> *… the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures. (UNISDR 2009)*

1.4.2.3. Summary

Coping and adapting and associated terms such as coping capacity, coping range, and adaptive capacity are used relatively frequently and often interchangeably in both the disaster risk management and climate change adaptation literature. Coping in the disaster risk management literature appears to have derived from an interest in understanding responses to disasters particularly amongst poorer populations, where little real alternative is seen for real risk reduction and development, and for bolstering bottom-up practice, and has increasingly been comingled with adaptation as disaster risk management practice has become more development oriented. Climate change adaptation has emphasized coping as a means of survival, but has not clearly distinguished coping mechanisms from other adaptation strategies or clarified the relationship between the two. The terms' meanings have evolved somewhat in recent years, but there have been no exhaustive efforts to disentangle their meanings.

That said, certain themes are relatively stable, particularly if coping is considered to be post-event (at least primarily): First, coping capacity and resilience are primarily concerned with the ability of a system to remain intact and maintain (or soon resume) normal function in the face of extreme stress. Normal function, it should be said, is not necessarily optimal function but merely connotes status quo prior to a disastrous event. Neither coping nor resilience necessarily transmit the idea of progress or getting out of the status quo, but instead both are primarily focused on returning to normalcy. Second, coping mechanisms are of greatest utility during the response phase of the disaster risk management cycle, and the processes of recovery, prevention, mitigation, and preparedness are not contained in coping capacity. The relationship between coping capacity and resilience has been characterized variably by different authors and remains unclear. Third, in contrast to coping, it seems most authors consider adaptation to be longer-term, more future oriented, and transformative. Overall, in the literature adaptation has a complex relationship with coping depending on whether coping is considered to be solely *ex* or both *ex* and *post ante*.

1.4.3. Adaptive and Maladaptive Risk Management and Insurance

The relationship between coping, adaptation, and the types of strategies that are truly adaptive under different climate change scenarios is garnering increasing attention (Lorenzoni, Pidgeon et al. 2005). There is concern that relying on certain coping strategiesmay not contribute substantially to adaptation over time and may undermine adaptive capacity given that coping often depletes resource stores. Adaptive decisions are those in which strategies are properly matched with changing risk distributions over a specified period of time and those that do not protect one population at the expense of another. Conversely, maladaptation occurs when risks and management strategies for a given period are not well matched, when a strategy increases other risks and ultimately undermines its own effect, when adaptation strategies shift unacceptable levels of risk onto other populations, or when cost-benefit horizons are too narrowly construed or short-sighted leading to bad risk management decisions. Many maladaptive strategies are also unsustainable, given the resource intensity of certain coping strategies and the depletion of capital and other stores (Risbey, Kandlikar et al. 1999). Most if not all types of maladaptation result from incomplete consideration and understanding of the complexity of dynamic systems as well as incomplete appreciation of the linkages between different risk management strategies and overall burdens of risk. As such, maladaptation can be construed as incomplete awareness and appreciation of system complexity in the risk management process.

1.4.3.1. Types of Maladaptation

There are several types of maladaptation, each correlated with a particular wrinkle in the interface between complex systems and risk management decisions. As Sterman and others who have studied dynamic complexity have noted (Sterman 2000), complexity can hinder evidence generation, learning from evidence, and evidence-based policy-making (Sterman 2006). Each of these problems results in a different type of maladaptation. Complexity, such as the difficulty in providing downscaled climate projections, limits knowledge of risk in risk management, so that some risks are increased by incomplete understanding of the hazard universe (or the universe of relevant risk management strategies). Also related to this is the issue of narrow disciplinary focus and short term perspectives, both of which can undermine proper calibration of risk management decisions.

Complexity that limits learning from evidence, often the result of heuristics or mental models that lead to “systematically erroneous but strongly self-confirming inferences” (Sterman 2006; also see Section 1.3.2.2), complicate policy action, even among experts. This has been observed in regards to flows of greenhouse gases into atmospheric stocks, which can drive misunderstanding of the costs and benefits of a “wait and see” approach to mitigation (Sterman 2008). This dynamic is also associated with the difficulty of weighing different levels of risk, some of which are more immediate but not catastrophic, while others feel more remote but potentially catastrophic, e.g. the risk associated with dwelling on a potentially unstable slope versus the risk of living far from one’s crops and the center of economic and cultural activity in a given region.

Complexity that inhibits evidence-based policy making and implementation typically results from difficulty with message diffusion, risk communication, and public suspicion over experts’ vested interests in the policy making process. This suspicion can lead to paralysis and failure to engage in appropriate risk management strategies despite the availability of compelling evidence. An example of this is the resistance to immunization policy recommendations, particularly regarding measles-mumps-rubella vaccination, which has been repeatedly correlated with disease outbreaks in communities with lower vaccination rates (Jansen, Stollenwerk et al. 2003). Altogether, those who have studied system dynamics term these maladaptive influences “policy resistance” and cite abundant examples, from the paradoxical increase in traffic often seen when roads are built or expanded (Sterman 2000) to the increase in forest fires seen with forest fire suppression (USDA Forest Service 2003).

Each source of maladaptation or policy resistance – complications with evidence generation, evidence interpretation, and evidence application – is relevant to the present discussion. The world’s climate is an exceedingly complex system with multiple feedbacks that are difficult to study and model. Attribution of observed climate changes to warming is challenging (see Chapter 3). This complicates generation of evidence relating climate change with its impacts, from injuries to property loss, and thus constrains identification of appropriate management strategies.

The World Health Organization’s estimate of the global burden of disease attributable to climate change is an example: as a result of methodological limitations in our ability to project extreme exposures and to confidently link certain climatic exposures with health outcomes, it focuses on only five major health outcomes (cardiovascular conditions exacerbated by increasing average temperatures, injuries and death associated with floods, illness and death from malaria, morbidity and mortality from diarrheal disease, and health impacts associated with malnutrition including disability and death). Given difficulties in modeling and projecting extreme event exposure, the study is limited to only a handful of important climate-health associations and does not evaluate others, e.g. excess mortality from severe heat waves, focusing instead only on health impacts of increases in temperature averages (McMichael 2004).

Finally, conflicting perceptions and messages related to climate change impacts and distrust of expert opinion and consensus findings related to climate change adaptation (Schrope 2001) complicate development and diffusion of a unified climate change risk management platform (see Section 1.3.2.2). The need to integrate indigenous coping mechanisms with conventional risk management strategies serves as another instance of this last complication. For example, modern early warning systems may fail if they do not integrate traditional mental models tied to indigenous coping mechanisms. This was the case in one unnamed country where local communities would not heed conventionally generated flood forecasts, instead waiting for their usual signal of flooding (UNFCCC 2003).

It should be noted that these sources of policy resistance do not map directly to specific categories of risk mismanagement, e.g. of inappropriate risk retention when risk might better be shared, reduction of risks that might be avoided, etc. Neither do they directly map to other common problems such as risk displacement, wherein adoption of a risk management strategy results in behaviors that increase overall risk exposure, or risk shifting, a related concern wherein risk management decisions reduce risk within one domain but increase risk outside of it. These types of mismanagement arise in many instances from centralization of power and lack of transparency in decision making, particularly in the case of risk shifting where international regulations are weak. The international trade in toxic waste, while not related to climate change, provides an excellent example of risk shifting and political failure in risk management secondary to global power differentials (Menkes 1998; Schmidt 1999; Hess and Frumkin 2000; Orloff, Falk et al. 2003).

1.4.3.2. Risk Amplification

Mismanagement of risk also may be maladaptive when it amplifies risks to those who remain exposed (or are newly exposed as a result of a maladaptive risk management strategy). There are abundant examples of this in the public health literature (Sterman 2006) as well as literature from other fields. The worldwide recession of 2008-2009 is an example from the financial sector, which had complex origins (Caballero, Farhi et al. 2008), including that risk managers (financial regulators in this case) failed to adequately enforce regulations relevant to a wide range of financial products designed to hedge against investment risks (Congleton 2009). Because risks were neither properly priced into financial transactions nor retained by the institutions that were making risky transactions, moral hazard occurred at multiple levels and losses were distributed widely over the public sector while gains had been distributed much more narrowly to private interests (Brill 2009; Okamoto 2009). Regulators are still struggling to find ways to reduce moral hazard and prevent similar risks from undermining the financial system in the future (Morgenson 2010). This instance illustrates the impact of maladaptive risk sharing and demonstrates the importance of how risks, in practice, are assumed and shared. The goal of risk sharing is to properly price risk so that, in the event risks are realized, there is an adequate pool of capital available to fund recovery. When risks are improperly priced and risk sharing is not adequately regulated, as can occur when risk sharing devices are not monitored appropriately, an adequate pool of reserves may not accumulate. When risks are realized, the responsibility for funding the recovery falls to the insurer of last resort, typically the public (see also Section 1.3.3).

Risk management decisions related to catastrophic events often pivot on thresholds: strategies that were conceived under one set of threshold assumptions can become maladaptive under another (Niemeyer, Petts et al. 2005). For example, levees protecting established communities in flood prone areas may be adaptive for anticipated floods of a certain magnitude, but maladaptive when the maximum projected flood height for a given period shifts. In such an instance, the levees exhibit both types of mal-adaptation: they represent a mismatch between projected risks and management strategies, and they promote assumption of greater risk by allowing for development in flood prone areas that feels safe but in fact is not. The maladaptive nature of certain strategies can be further amplified by mal-distribution of risk associated with risk displacement and moral hazard (assumption of increased levels of risk when risk management schemes are in place). This is the case in coastal development, wherein property insurance for beachfront properties is effectively subsidized by inland residents, as discussed further below.

In climate change adaptation literature the mismatch between adaptive strategies and needs has been characterized as the potential for regret, namely:

> The “regrets” that are experienced when planning for climate change in the present (*ex ante*) based on one set of climate expectations that later on (*ex post*) turns out to be “wrong”. … These regrets can be translated into economic opportunity costs, based on the losses that society incurs by not making the best *ex ante* choice. In situations where the range of possible climate changes that could occur becomes very broad (or very uncertain),

> then the decision-making framework needs to be changed so that the robustness of adaptation decisions over a wide range of climates is more important (i.e. has lower economic regrets) than making a decision that is optimal for one or a small number of climate states. (Callaway and Hellmuth 2007)

Identifying "no regrets" adaptation policies in response to climate change can, as a result, become a dizzyingly complex exercise in comparative risk assessment involving many assumptions that complicate the policy making process and introduce substantial potential for policy resistance. Certain approaches such as social risk management have been advanced as useful lenses to facilitate no-regrets adaptation (Heltberg, Siegel et al. 2009), though the potential for several types of policy resistance remains even with many types of intentional adaptation planning (Urwin and Jordan 2008).

1.4.3.3. Mal-Adaptation and Insurance

In many countries a principal justification for catastrophe insurance is to provide social 'solidarity' or risk sharing without adequate consideration of the underlying risk differentials. A classic example of this is the French Cat Nat system (de Marcellis-Warn and Michel Kerjan, 2001), where all property insured pays an additional fixed percentage to support a central State Backed Reinsurer fund. The fund pays out for claims when a Cat Nat event is announced (by ministerial decree) in a municipality. One progressive feature of the system is that the deductible is raised after a claim has been made so that a claimant will have to pay progressively greater proportions of each subsequent loss. However, by virtue of the fact that any new property will be covered under a flat rate arrangement, the system effectively subsidizes further development in risky locations such as river flood plains, another example of moral hazard discussed above (see Section 1.3.3).

Inadvertent risk subsidies are also facilitated in regulated insurance systems in which the rating resolution is too coarse to adequately account for the underlying gradients of risk, as for example in Florida (Grace and Klein, 2007, Klein, 2007, Grace and Klein, 2009). The greatest beneficiaries of insurance rates averaged over larger areas are those with beach front properties, which tend, for the acknowledged amenity value, not only to have the highest risk but also to be the most expensive.

To design an insurance system that motivates adaptation requires that technical rates – rates that properly reflect empirically determined levels of risk – be established and accepted at the highest relevant resolution, a difficult prospect. Even in countries with free market flood insurance systems, insurers may be reluctant to charge the full technical rate for the risk in acknowledged high hazard flood plains, as consumers have come to assume that insurance costs should be relatively consistent by location, while the differential technical rates implied by flood risk, for example, may vary by an order of magnitude and more. Without charging technical rates for the risk, however, it is difficult to use pricing signals to motivate adaptation strategies such as flood proofing or elevating the ground floor of a new development (Lamond et al., 2009). As mechanisms to incentivize adaptation become even more important in places where levels of risk are rising, climate change may prompt reconsideration of structures and policies that promote maladaptive risk management processes.

1.4.4. Learning, Coping, and Climate Change Adaptation

Pursuing a "no regrets" approach to climate change adaptation and development can be remarkably complex. Similar to *"primum non nocere"* ("first do no harm") in medicine, "no regrets" serves as a first principle but in fact provides little guidance for generating, interpreting, and applying evidence in service of enlightened policy, particularly in the dynamically complex context of climate change and development. In practice, identifying and implementing "no regrets" strategies requires an enhanced approach to managing complexity, particularly regarding feedback mechanisms, learning promotion, and evidence interpretation as noted in 1.4.4.1 above. The new methods for developing robust uncertainty management strategies noted in 1.3.4.1 are beginning to address some of these challenges (Lempert 2002).

Of particular relevance to the topic of coping and adapting is the distinction between different types of learning, including single-loop and double-loop learning processes (see Figure 1-5; Argyris and Schon, 1978). In single-loop learning processes, like steering a car to correct its course when it veers, the rules are followed, i.e. data is integrated and acted on but the underlying mental model used to process the data is not changed. In double-loop learning, the rules are changed, i.e. data are both acted on and used to change underlying mental models. Continuing the driving analogy, double-loop learning might entail regular examination of population-based crash location data and decisions to change road signage, speed limits, police patrols, and other interventions in order to reduce crash incidence. Single-loop learning is relatively static while double-loop learning is iterative and adaptive. Some authors also distinguish triple-loop learning, or learning about learning, i.e.reflection on how we think about rules rather than on how to follow them or change them to better suit the circumstances. In triple-loop learning about risk, the social structures, cultural mores, and other structures that mediate constructions of risk are changed in response to evidence that these deep social structures are not serving a larger agreed upon goal. Extending the example still further, triple loop learning could, for example, entail a shift in urban design away from the automobile toward more dense development, public transit, and design principles that facilitate walking, cycling, and other human-powered forms of transit.

[INSERT FIGURE 1-5 HERE
Figure 1-5: _________________________ (Sterman, 2006).]

There are clear parallels with coping, adaptation, and what some have termed transformation (Kysar 2004). Single-loop learning, like coping, tends to be reflexive, survival oriented, and occurs over a relatively brief period of time. Double-loop learning, like adaptation, tends to be anticipatory, future-oriented, and most effective (in a dynamic context) when the process is reiterated repeatedly over time. In some instances, triple-loop learning may lead to a more transformative change wherein social structures, institutions, and constructions that contain and mediate risk are recast to accommodate more fundamental changes in world view (Pelling 2010).

Without suggesting that coping mechanisms are unsophisticated or unschooled, and noting that coping can be necessary and protective in many circumstances, the distinction between single-, double-, and triple-loop learning highlights the limitations of over-reliance on coping as a strategy, particularly when circumstances are changing. In such instances, reliance on coping not only does not confer advantage but in fact may result in a behavioral mismatch for new environments and conditions. Of course, not all coping mechanisms are categorically reflexive; some are complex learned strategies that have developed over long periods of time and been tested against observation and experience. In this way, the role of learning and the equation of single-loop/coping - double-loop/adaptation - triple-loop/transformation provides a link to the Yohe and Tol (2002) discussion of coping and adaptation, in which coping mechanisms and ranges can shift over time. While they do not refer to learning loops or to transformation, these processes are operative in shifting coping range according to their analysis. Extending their analysis, over time, as iterative adaptation shifts the coping range, societies may come to inhabit a categorically distinct sustainability basin as a result of third-loop learning.

Focusing on learning and the role of coping and adaptation in the learning process suggests that there may yet be room for a productive association between the two that can facilitate climate change adaptation. In particular, to the extent that coping mechanisms can be catalogued along with the contexts in which they are most applicable, they may inform climate change adaptation activities by enabling survival in the face of extreme stress and allowing for a return to relatively normal function, wherein more aspirational, development oriented processes would prevail. Understanding historical coping mechanisms can also provide fundamental insight into how societies perceive and act on risk, i.e. how they filter the complexity associated with risk assessment and risk management. Such insight is a key component of the process of learning to manage dynamic complexity, which is at the heart of climate change adaptation.

1.5. Structure of this Report

This report is organized into three major sections. The first four chapters focus on generic questions that are common to managing adaptation to climate change, extreme events, and disaster at any level of governance and any type of social aggregation. The second section focuses on distinct levels of governance and social aggregations, and how such adaptation may be coordinated with the non-climate goals and objectives of each. Finally, a chapter on case studies focuses on experience gained from specific instances of extreme impact and disaster.

Chapter 2 assesses literature on the key determinants of climate risk, namely hazard, exposure and vulnerability. A particular focus is the connection between near term experience and long term adaptation. Key questions include whether adapting better to current hazards improves adaptation to longer-term climate change, how natural hazards research informs the question of how adaptation may address or reduce the risk of "dangerous" climate change, how near-term decisions and adjustments constrain or enable future vulnerability and capability to adapt, and what insights from hazard assessment and warning systems might apply to climate change?

Chapter 3 focuses on changes in climate extremes and the impacts of those extremes on the natural physical environment. The chapter reviews expected changes in the frequency and intensity of heat waves, tropical storms, El Nino, monsoons, etc, based on literature assessed by WGI during AR4, and revises this assessment based on literature published subsequently. In addition, the chapter examines impacts such as extremes of sea level, drought, and flooding in order to provide a quantitative physical basis for the chapters that follow.

Chapter 4 explores how changes in such physical impacts assessed in Chapter 3 may translate into extreme impacts on and disaster in human systems and ecosystems. Impacts of extreme events depend on the interaction of the physical changes with exposure and vulnerability, both of which will also change over time. A key issue is the nature of both observed and expected trends in hazards, the latter resulting from trends in both physical and social characteristics. The chapter assesses these questions from both a regional and a sectoral perspective, and examines the economic costs of such changes.

Chapters 5, 6, and 7 ask a common set of questions: What is the appropriate distribution or allocation of responsibility for the management of the risks from climate extremes and disasters? Is the present allocation of tasks and responsibilities at the local, national, and international levels satisfactory or are there options that might facilitate improved performance? Who does and who could shoulder which activities and which roles? At the same time, the discussions recognize the importance of other levels of government (e.g., village, community) as well as individual, non-governmental, private sector, and other civil society institutions and arrangements. These three chapters explore these questions from 7 perspectives: subsidiarity, the social contract, systematic risks, economic efficiency, legal obligations, development as disaster reduction, and harmonization.

Chapter 5, focusing on the local level of housing, buildings, land use, and warning systems, and evaluates the efficacy of current preparedness and responses to extremes and disasters to extract lessons for the future. Impacts and adaptation, and the cost of risk management, are assessed through the prism of diverse social aggregations and means for cooperation, as well as a variety of institutional arrangements. Chapter 6 explores similar issues at the national level, where the key elements include, *inter alia*, food and agriculture, forests, fisheries, and public health, and national institutional arrangements such as national budgets, development goals, and planning. Chapter 7 carries this analysis to the international level, where the emphasis is on institutions, organizations, and practices which characterize international agencies and cooperative arrangements. This chapter also discusses integration of responsibilities across all governmental scales.

Chapter 8 assesses how disaster risk reduction strategies can advance climate change adaptation and promote a more sustainable and resilient future with a focus on the literature that considers whether an improved alignment between climate change responses and sustainable development strategies may be achieved.

Chapter 9 closes this report by presenting case studies in order to identifying lessons and best practices from past responses to extreme climate-related events and extreme impacts. Cases illustrate concrete examples of the disasters types, methodologies, and subsequent responses discussed in the other chapters in the context of specific applications, providing a key reference point for the entire report.

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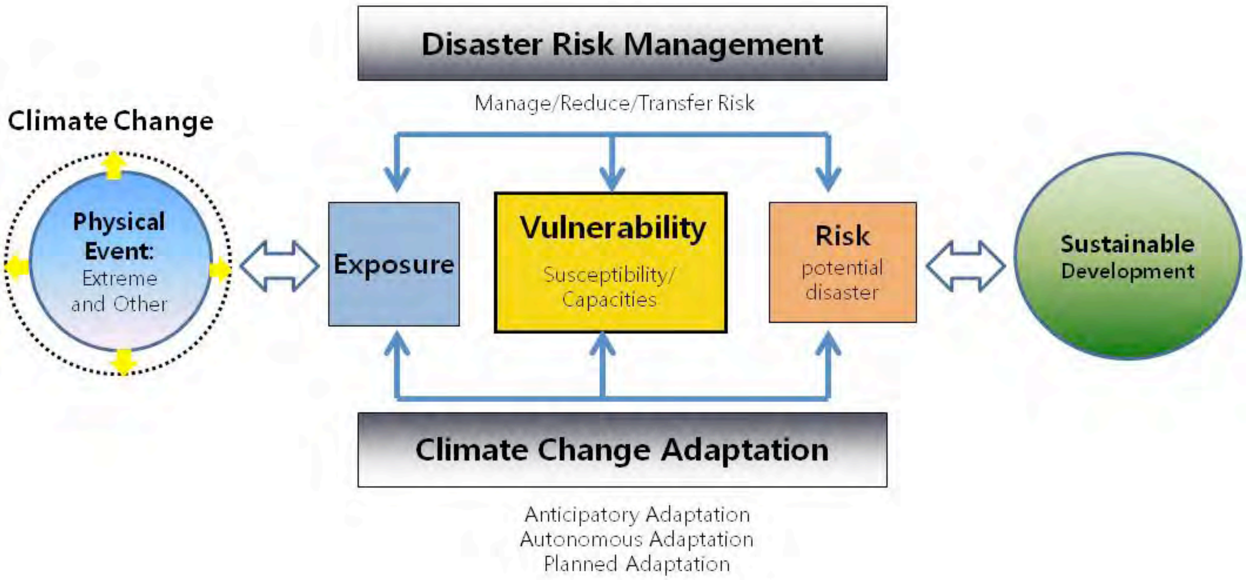


Figure 1-1: The key concepts and scope of this report.

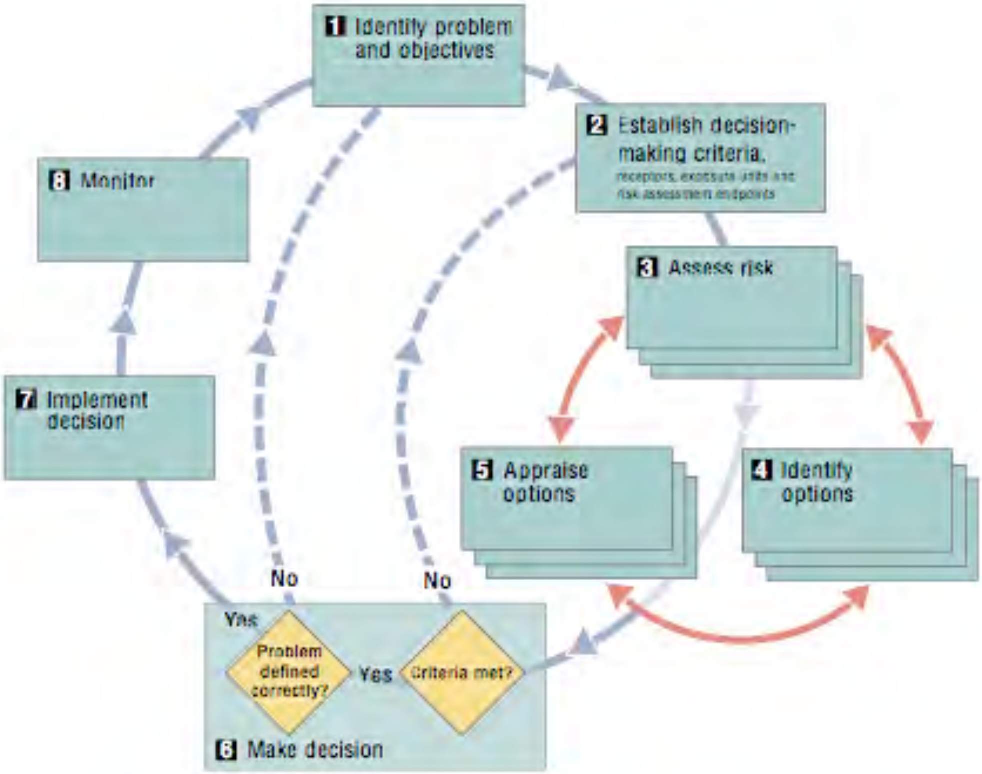


Figure 1-2: One example of an iterative risk management approach, developed and widely applied by the UK Climate Impacts Program (Willows and Connell 2003).

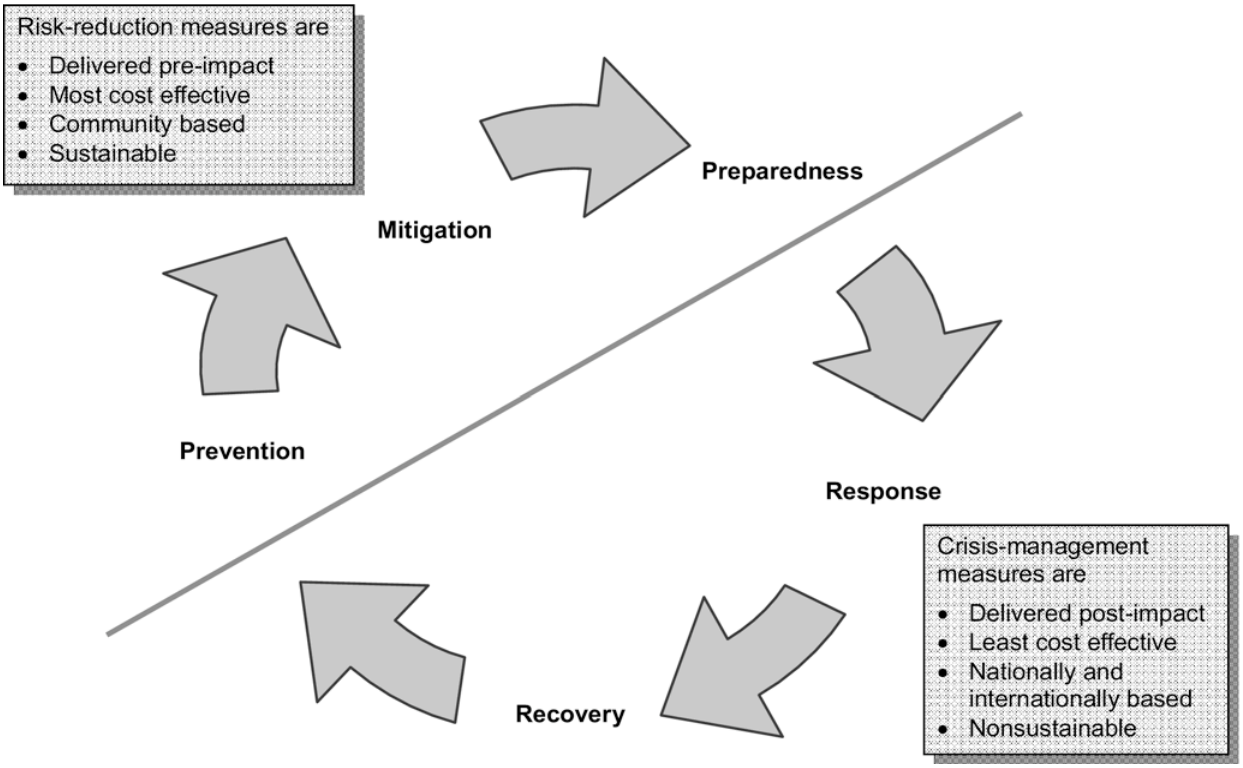
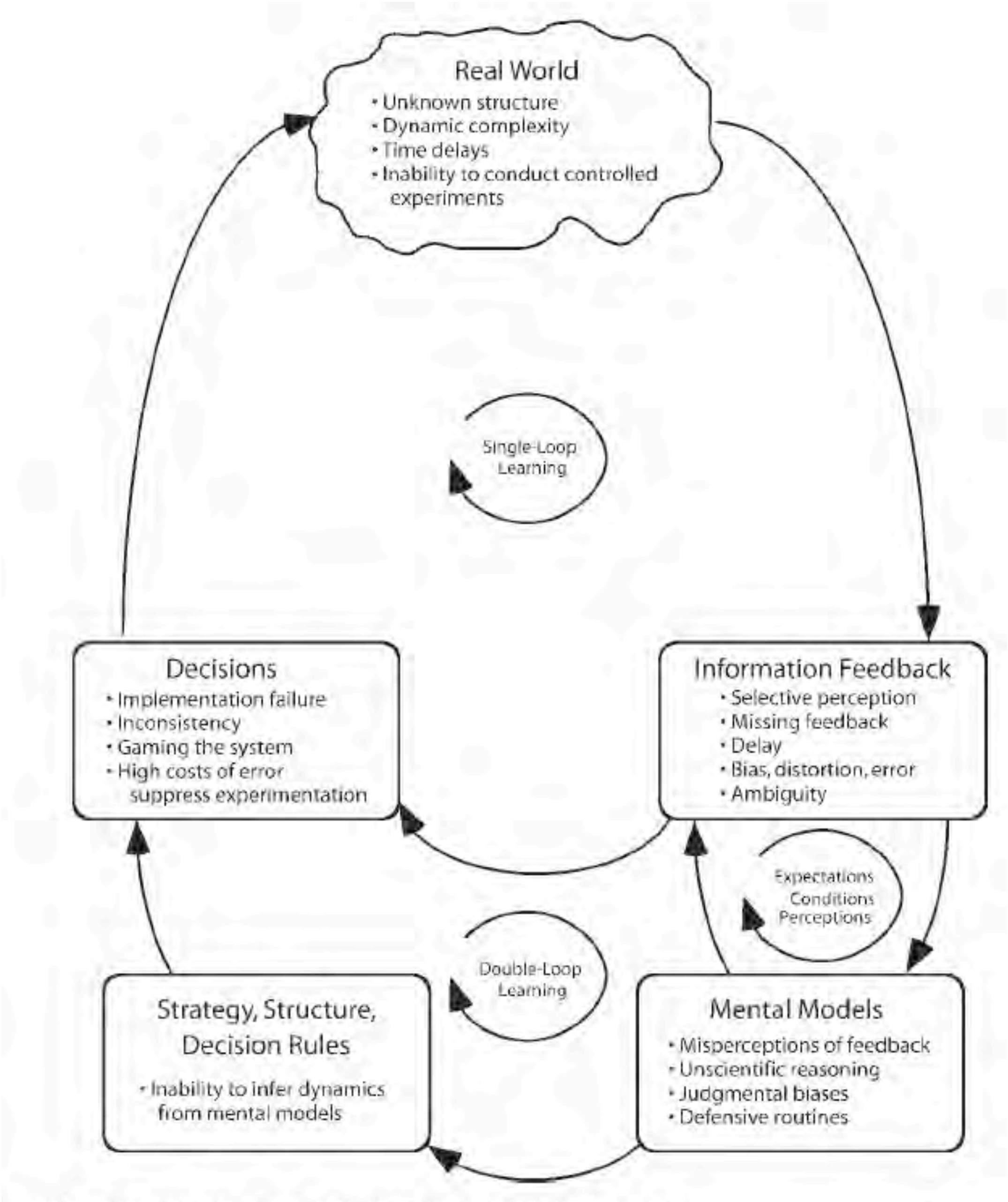


Figure 1-3: ______________________ (Keim, 2008).

Figure 1-4 Evolution of climate change adaptation and disaster risk management.

PLACEHOLDER: Figure will be a timeline of disaster risk management and climate change adaptation that illustrates significant dates for both disciplines / communities and highlights recent overlapping activities, conferences, and significant dates in the development of shared principles and practice.



Note. The diagram shows the main impediments to learning. Arrows indicate causation.

Figure 1-5: ________________________ (Sterman, 2006).

Chapter 2. Determinants of Risk: Exposure and Vulnerability

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Contents

Executive Summary

Vulnerability and exposure are key determinants of disaster risk. Trends in vulnerability and exposure are the main causes behind observed trends in disasters losses. A better understanding of risk, including vulnerability and exposure, is essential for adaptation strategies and practices. [2.1, 2.2, 2.7, 2.8]

Disaster risk originates from a combination of social processes and their interaction with the environment. Determinants of risk include hazards, exposure and vulnerability. The causal factors of vulnerability are susceptibility/exposure, eco-social and economic fragility and lack of resilience. Exposure is the inventory of assets and interrelations of human systems that can be affected. Resilience includes the capacity to anticipate, cope and recover. [2.3, 2.4]

Vulnerability and exposure are highly context specific, including physical, environmental, economic, social, cultural, institutional and governance dimensions. Vulnerability is highly differentiated, including by wealth, gender, age, race/ethnicity/religion, disability, and class/caste. Vulnerability and exposure are very dynamic, because the context is non-stationary. [2.2, 2.5, 2.7]

The evolution of vulnerability and exposure partly depends on the approaches taken in dealing with hazards and change. Such approaches range from a focus on the short term, which may inadvertently lead to maladaptation, to long-term strategies that explicitly foster resilience. Lack of capacity to cope and adapt leads to vulnerability. [2.4]

Key drivers of trends in vulnerability and exposure include population growth and changing demographics, urbanization, economic development, environmental degradation, science and technology, as well as institutional and governance dimensions. Important complexities arise from accumulation of risk, dynamic changes in vulnerabilities, and different phases of crises and disaster situations. [2.7]

Climate change has the potential to affect not only the frequency and intensity of climate and weather extremes, but also vulnerability and exposure, for instance through impacts on the number of people in poverty or suffering from food and water insecurity, the social segregation of society, diminishing human and social capital, general health levels especially amongst the poor, where people live, and governance**.** [2.7]

Comprehensive assessment and effective communication of risk are important for reducing vulnerability. However, there are methodological and data gaps in risk assessment that need to be filled to inform proper interventions (adaptation). Vulnerability profiles -- summaries of data and other information on who and what is vulnerable when and where -- can help to quickly identify the determinants of risk for a system and sectors at risk. Vulnerability and risk indicators, criteria or indices are important tools for risk monitoring and vulnerability analysis. However, no indicator fits all purposes, and improvements are needed to better capture dynamic aspects of vulnerability and risk, including societal response. [2.2, 2.6, 2.8]

Impediments to information flow (including bottom-up and top-down) are key determinants of risk. Effective communication of risks requires new formats of communication that deal appropriately with uncertainty and complexity. [2.8]

2.1. Introduction and Scope

Many adaptation efforts have started to address the implications of potential changes in the frequency and intensity of extreme events. To properly assess the impact of such changes, a good understanding of exposure and vulnerability to climate-related hazards is essential. However, exposure and vulnerability are not simply a steady baseline against which risk evolves primarily due to changes in hazards. In fact, changes in exposure and vulnerability generally create larger and faster trends in risk than changes in climate and weather extremes due to anthropogenic climate change (e.g. Bouwer *et. al.*, 2007; Pielke and Landsea, 1998). Hence, effective strategies and practices to manage future climate risk depend on a solid understanding of the dimensions of exposure and vulnerability to climate-related hazards, as well as a proper assessment of trends in those dimensions. This chapter aims to provide that underpinning of the SREX, by exploring the determinants of risk and thus demonstrating the fundamental entry points for risk reduction and adaptation.

In that context, it is important to note that the constituency that supports improved risk management has historically proven limited in bringing about many of the changes that have been recommended by disaster risk reduction and climate adaptation researchers alike, especially those that focus on modifying social and development pressures in order to reduce vulnerability. Key to addressing present and future risks include integration of bottom up and top down information, clarifying the risks of living in a particular location, and overcoming impediments to the flow of information across scales. Despite the significant efforts of these communities, the vulnerability of many individuals and communities to natural hazards continues to increase considerably (Thomalla *et al*., 2006). Behind the analytical questions regarding the transparency of risk, are broader questions about the public sphere and the public goods provided – or not provided -- by governments, civil society organizations and market actors. These questions become particularly pertinent in the context of climate change, which in many cases has the largest impacts on those already vulnerable to current climate variability and extremes. Answers to these questions must address not just information about risk, but particularly appropriate instruments, incentives and institutions to better manage risk in the context of development (e.g. Bettencourt *et al.,* 2006). These issues will be explored more explicitly in chapters 5, 6, 7 and 8, but they do shape the analytical perspective of this chapter in assessing the determinants of risk.

The first sections of this chapter elucidate the conceptual determinants of risk, showing that risk originates from a combination of social processes and their interaction with the environment (2.2-2.3), and highlighting the role of coping and adaptive capacities as determinants of risk (2.4). The subsequent descriptive sections describe the different dimensions of vulnerability and exposure (2.5), a set of vulnerability profiles in specific sectoral contexts (2.6), and finally trends in vulnerability and exposure (2.7). Given that exposure and vulnerability are highly context specific, these sections are by definition limited to a general overview. A methodological discussion (2.8) of approaches to identify and assess risk provides indications of how the dimensions of exposure and vulnerability can be explored in specific contexts, such as adaptation planning, and the central role of risk perception and risk communication. The chapter concludes with a crosscutting discussion of risk accumulation, the nature of disasters, and barriers to overcome (2.9) and research gaps (2.10).

2.2. Defining Determinants of Risk: Hazard, Exposure, and Vulnerability

Disaster risk can be defined as the probability of future damage and loss associated with the occurrence of environmental hazards where levels and types of loss are determined by the levels of exposure and vulnerability of society (UNDRO, 1980; Cardona, 1990; UNISDR, 2004, 2009b; Birkmann, 2006a/b). Risk is the result of the interactions in time and space of probable physical events with exposed vulnerable elements of the social systems (Cuny, 1984; Davis and Wall, 1992). Through such interactions, these physical events are transformed into hazards with the potential to generate future loss and damage. It is in the latency of risk that the opportunity for risk prevention, mitigation and transfer exists, employing diverse adaptation or disaster risk management principles, strategies and instruments (Lavell, 1996, 1999a). Disaster risk management may be defined as a social process that searches to reduce, predict and control disaster risk drivers in a development framework, by means of the design and implementation of appropriate policies, strategies, instruments and mechanisms (Cardona and Barbat, 2000). Effective risk reduction and adaptation requires shift from focus on the disaster event towards understanding of disaster risk (Cardona *et al.,* 2005).

A disaster itself may be defined as a social condition whereby the normal functioning of society has been severely interrupted by the levels of loss, damage and impact suffered (Cardona, 1990; Alexander, 1993, 2000; Quarantelli, 1998; Birkmann 2006b). This damage and loss may, under certain circumstances, reach such levels and consequences that it can be defined as a large-scale “disaster” or “catastrophe”. On the other hand, events with lower levels of loss and damage, (albeit still with high impacts on lives and livelihoods at smaller levels of aggregation, such as the household, community or municipality), it is now common to talk of small- and medium-scale disasters (Marulanda *et al.,* 2008, 2009, 2010; United Nations, 2009). Disasters, large or small, are the product of a complex relationship between the physical world, the natural and built environment, and society, its behaviour, functioning, organization and development (Quarantelli, 1998). At the same time the disaster itself leads to new social processes and new or transformed risk conditions. Disasters associated with environmental hazards reflect and signify unmanaged risk and may also be seen as representing unresolved development problems (Westgate *et al.*, 1976; Wijkman and Timberlake, 1984). Risk is a continuum, and disaster one of its many “moments” or “materializations” (Lavell, 2005; ICSU-LAC, 2010).

The concept of hazard is used to refer to a latent threat that can be expressed as the potential occurrence of natural, socio-natural or anthropogenic events that may have physical, social, economic and environmental impact in a given area and over a certain period of time (White, 1973; UNDRO, 1980; Cardona, 1990; Birkmann, 2006b). Each hazard is characterised by its location, frequency and intensity. A natural hazard means the potential occurrence of an extreme geophysical or hydrometeorological event that may cause severe effects to exposed and vulnerable elements (UNDHA, 1992). The study of hazards typically involves the natural, earth- and applied sciences.

At present the effects of climate change on frequencies and intensities of hazard events are a key field of research (ICSU-LAC, 2010). In this context hazards can be the extreme weather phenomena themselves –such as intense tropical storms–, or they can be the result of the physical impacts of climate extremes on the natural environment, especially through the local hydrology –such as a deficit or excess in rainfall that results in a drought or flood. Subsequently, these hazards may have impacts or adverse effects on natural (ecosystems) and human systems (socio-economic).

When the intensity or recurrence of hazard events is partly determined by environmental degradation and human intervention in natural ecosystems, the origin of hazard can be considered as socio-natural. These hazards are created where human activity intersects with natural ecosystems. Changes in the environment and global climate change are the most notable examples of socio-natural hazard phenomena (Lavell 1996, 1999a).

Vulnerability refers to the propensity of exposed elements such as human beings and their livelihoods to suffer damage and loss when impacted by single or diverse hazard events (UNDRO, 1980; Timmerman, 1981; Maskrey, 1984; Cardona, 1986, 1990; Liverman, 1990; Cannon 1994, 2006; Blaikie *et al.,* 1996; UNISDR, 2004, 2009b; Birkmann, 2006b, Thywissen, 2006. In the context of disaster risk, vulnerability, its facets, factors and levels are generally seen as a result of defined social processes. That is to say, vulnerability is the most palpable manifestation of the social construction of risk (Aysan, 1993; Blaikie *et al.,* 1996; Wisner *et al.,* 2004). The physical world and the potential for hazard it presents are given a social dimension and significance by human behaviour and its results in terms of the organisation, structuring and functioning of society and its support elements (Wilches-Chaux, 1989; Wisner *et al.,* 2004). Such social construction includes (ICSU-LAC, 2010):

- How human action influences the levels of exposure and vulnerability in the face of different physical events.
- How human intervention in the environment (degradation or transformation) leads to the creation of new hazards or an increase in the levels or damage potential of existing ones (socio-natural).
- How human perception, understanding and assimilation of the factors of risk influence their reactions, prioritization and decision making processes.

The term vulnerability has been employed by a large number of authors in other contexts of social sciences to refer to disadvantaged conditions. Thus, for instance, people refer to vulnerable groups when they talk about the elderly, children or women, without specifying what these groups are vulnerable to. However, following on from what we have stated above, it is important to ask ourselves: Vulnerable to what? (Wisner *et al.,* 2004) In other words, hazard and vulnerability are mutually concomitant and lead to risk. If there is no hazard it is not feasible to be vulnerable when seen from the perspective of the potential damage or loss the occurrence of an event might signify. In the same way, no hazard can exist for an element or system if such an element is not exposed and vulnerable to the potential event. Even though this might seem to be an unnecessary subtlety, it is important to make this distinction, given that the adjective vulnerable is employed in different ways in problem areas other than the disaster field (psychology, public health, social protection, poverty studies, etc). A population might be vulnerable to hurricanes, for example, but not to earthquakes or floods; notwithstanding other ways of approaching vulnerability help show synergies and trade-offs useful for risk understanding (Alwang et al 2001; Cardona et al, 2003; Lopez-Calva and Ortiz, 2008; UN, 2009).

Table 2-1 presents a compilation of the definitions of vulnerability gathered and categorised by domain; i.e. risk assessment, climate change, social/institutional vulnerability, integrated. An extensive review of the terminology was carried put by Thywissen (2006) and includes a long list of definitions used for the term vulnerability.

[INSERT TABLE 2-1 HERE:
Table 2-1: Definitions of the term vulnerability as described in the literature reviewed.]

Disaster risk and disaster, in summary, originate from a combination of social processes and their interaction with the environment. The notion of social construction of risk is now widely used to capture the idea that society, in its interaction with the changing physical world, constructs disaster risk by transforming physical events into hazards through social processes that increase the exposure and vulnerability of population groups, their livelihoods, production, support infrastructure and services (Chambers, 1989; Cannon, 1994; Wisner, 2006a; Carreño *et al.*, 2007a). Disaster risk and disasters have been constantly on the rise over the last five decades. This trend may be exacerbated by climate change, unless concerted actions to reduce risk and adapt to the changing climate are not enacted, including corrective and prospective interventions to address disaster risks (Lavell, 1996, 1999a, 2005).

From the research angle, natural and engineering (applied) sciences provide a basic platform and understanding of environmental processes (in terms of geomorphology, ecology, etc.) and physical vulnerability. On the other hand, social science provides an understanding of the social, economic, cultural and political rationale for the types of intervention experienced (Cutter, 1994; Kasperson *et al.,* 1988).

The challenge for the natural and applied sciences is to provide relevant information to individual and collective decision makers, especially on potential consequences and possible strategies to reduce risk. However, basic scientific information is not enough. Effective risk management also requires a good understanding of the underlying vulnerabilities, as well as effective communication and dissemination of risk knowledge. As disaster risk is not an autonomous or externally generated circumstance to which society reacts, adapts or responds (as is the case with natural phenomena or events per se), but rather, the result of the interaction of society and the natural or built environment, it is in the knowledge of this relationship and the factors influencing it that effective risk management can be achieved (Susman *et al.,* 1983, Comfort *et al.,* 1999; Renn, 1992; Vogel and O'Brien, 2004). This requires varying types of relationships and coordination between social and basic, natural or applied sciences (ICSU-LAC 2010). However, despite the many calls for interdisciplinary and trans-disciplinary methods and research, efforts to understand and address disaster risk are still dominated by partial approaches and contributions whereby the different sciences and disciplines contribute their specialized knowledge to the understanding of diverse facets of the problem, all of undoubted importance, but which do not define or delimit the overall disaster risk as such (ICSU-LAC, 2010). This is why some authors suggest that as yet we do not have an integrated conceptual framework, a common theory, for studying risk, which is jointly adopted or understood by the specialised sciences or disciplines (Cardona, 2004).

2.3. Vulnerability Factors

The notion of risk, in general, denotes simultaneously a possibility and a reality. It is an abstraction of a transformation process and reflects an undesirable state of reality which has not yet materialized. The social materialization of risk can be understood by thinking risk in terms *a becoming-real* of a social construction (Beck, 2000, 2008; Adam and Van Loon, 2000). If the distinction between reality and possibility is accepted, then risk could be understood as the possibility that an undesirable state of reality (adverse effects) will occur as a result of natural or socio-natural events (Luhmann, 1990). Subsequently, risk can be something measurable in probabilistic terms, what is useful for resource allocation, but also its intervention can be based on social values and preferences (Renn, 1992).

The conceptual frameworks used to understand and interpret disaster risk and the associated terminologies have not only varied over time, but also differ according to the disciplinary perspective considered. Although researchers and professionals working in the disaster areas may believe that they are talking about the same concept, serious differences exist that impede the decision-making effectiveness; i.e. successful, efficient, and effective risk reduction implementation (Cardona, 2004).

As stated previously, risk is the result of the interaction in time and space of exposed and susceptible persons, their livelihoods and support infrastructures and, potentially damaging physical events. Therefore, understanding risk minimally requires knowledge about (ICSU-LAC, 2010):

- *Hazards*, including how human intervention in the natural environment leads to the creation of new hazards
- *Exposure*: how persons, property, infrastructure and goods and the environment itself are exposed to potentially damaging events (due to their location and physical susceptibility)
- *Vulnerability* of persons and their livelihoods, including the allocation and distribution of social and economic resources in favour of, or against the achievement of resistance, resilience and security.

In other words, vulnerability is the "state of reality" that underlies the concept of disaster risk. It is the causal reality that determines the severity of damage when a hazard event occurs. Vulnerability reflects susceptibility, the intrinsic predisposition to being affected (lack of resistance); the conditions that favour or facilitate damage (lack of resilience). IPCC defines vulnerability as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2007). On the other hand, UNISDR defines vulnerability as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of hazards (UNISDR, 2009b). Many believe that it is not possible to assess vulnerability however it is fundamentally important to understand how vulnerability is generated, how it increases, and how it builds up (Maskrey, 1984, 1989; Lavell, 1996, 1999a; O'Brien *et al.,* 2004b; Cardona, 1996, 2004, 2010). The evaluation and follow-up of vulnerability and risk is needed to make sure that all those who might be affected, as well as those responsible for risk management, are made aware of it and can identify its causes (Maskrey, 1993a/b, 1994b, 1998; Mansilla, 1996). To this end, evaluation and follow-up must be undertaken using methods that facilitate an understanding of the problem and that can help guide the decision-making process.

2.3.1. Conceptual Frameworks of Vulnerability and Disaster Risk

In general, vulnerability describes a condition of people that derives from the political and economic context. In this sense, vulnerable groups are not only at risk because they are exposed to a hazard but as a result of marginality, of everyday patterns of social interaction and organisation, and access to resources (Bankoff, 2004; Morrow, 1999). Thus the effects of a disaster on any particular household result from a complex set of interacting conditions. Cannon (2006) suggests that disparities in income distribution, wealth and power are ultimately the major factors of vulnerability. Wisner (1993) then suggests that the notion of vulnerability could be expanded to include also processes and effects of marginalisation. Wisner (2003) defines guidelines to generate vulnerability profiles, taking into consideration sources of environmental, social and economic marginality. However, it is important to keep in mind that people and communities should not be perceived only or mainly as victims, and this to avoid evading the relevant problem of what causes vulnerability (Cannon, 2000). Households and communities are active managers of vulnerability (Pelling, 1997, 2003).

The concept of vulnerability clearly involves varying magnitudes: some people experience higher intensities of impact than others (Wisner *et al.,* 2004). Allen (2003) and others suggest that there are theoretical, pragmatic and ethical reasons to suggest that the community scale is the most appropriate scale at which to target vulnerability, yet some vulnerability issues can only be addressed by governments or even at supranational level. However, mainstreaming of appropriate disaster risk management into development planning faces obstacles such as lack of political will and geographic inequity (UNDP, 2004).

Twigg (2001), Birkmann (2005) and Birkmann (2006) give an overview of conceptual frameworks, definitions and approaches for assessment of vulnerability to natural hazards. Cutter *et al. (*2008a,b) also carry out a comparative analysis of vulnerability frameworks. Adger (2006) reviews different approaches from the human ecology perspective (i.e. entitlements, analysis of the underlying causes of vulnerability), the natural hazard perspective (i.e. identification of vulnerable group and regions) and the Pressure and Release (PAR) model. Füssel and Klein (2006) review the evolution of the concepts and methods of vulnerability assessment in the climate change community, and include a glossary of the main concepts underlying the IPCC approach. Schröter *et al.* (2005) uses the notion of coupled system to define and assess global change vulnerability. Adger and Brooks (2003) also draw a link between vulnerability and global environmental change.

Thomalla *et al.* (2006) and Mitchell and van Aalst (2009) examine commonalities and differences between the climate change adaptation and disaster risk reduction communities, and identify key areas of convergence. It results that the two communities perceive differently the nature and timescale of the threat: if impacts due to climate change are surrounded by uncertainty, considerable knowledge and certainty exists about the events characteristics and exposures related to extreme environmental conditions, due to historical experiences. In the other hand, the disaster risk management community is increasingly adopting an anticipatory and forward-looking approach, but bringing it in-line with the longer-term perspective of the climate change community on future vulnerabilities. Climate change adaptation increasingly places emphasis on improving the capacity of governments and communities to address existing vulnerabilities to current climate variability and climatic extremes (Thomalla *et al.,* 2006). O'Brien *et al.* (2004b) pleas for an integration of 'underlying causes' of vulnerability and adaptive capacity in climate change impact assessments rather than focusing on the adaptive capacity and technical measures only.

The PAR model (Blaikie *et al.,* 1994; Wisner *et al.,* 2004) links discrete risk with political economy of resources and normative disaster management and intervention (Adger 2006). The framework is common to risk research and places weight on the social conditions of exposure. Risk is explicitly defined as a function of the perturbation, stressor, or stress and the vulnerability of the exposed unit (Turner *et al.,* 2003). According to Bankoff (2004), the PAR model is still a-historic and reductive; time is treated like an independent variable, and social memory, although difficult to measure, could be a crucial influence on behaviour and perceptions of vulnerability. It fails to adequately address the coupled human–environment system associated with the proximity to a hazard (Cutter *et al.,* 2008a,b). The Sustainability Livelihoods Framework developed by the Department for International Development (DFID) includes three main categories of vulnerability factors. Trends: population, resources, economic, politics and technological; shock: human health, natural, economics, conflict and crop/livestock health shocks; seasonality: seasonal shift in prices, production, food availability, employment opportunities and health (Cannon, 2006). Cardona (1999a,b, 2001) develops and *holistic approach to risk assessment* based on three main components: physical exposure and susceptibility, socioeconomic fragility, and lack of resilience or capacity to anticipate, cope and recover. Similarly, the IPCC definition focuses on vulnerability as a function of exposure, susceptibility or sensitivity to damage and adaptive capacity, including the capacity to recover from impacts (McCarthy *et al.,* 2001; IPCC, 2007; O'Brien *et al.,* 2008). The application of the framework used in Barbat *et al.* (2008) links physical vulnerability to other dimensions of vulnerability and allows understanding the social construction of risk and alternatives for risk reduction in the development context. The disaster risk and reduction and climate change communities aim at integrating the environmental and social perspectives. In this view, vulnerability is a function of the biophysical system and social response and how this manifests itself locally, or the hazardousness of place (Cutter *et al.,* 2008a/b). The vulnerability framework developed by Turner *et al.* (2003) is structured around the concept of coupled human–environment system and accounts for interactions in the system's responses to hazards and its vulnerability. This vulnerability framework is representative of the global environmental change community and defines vulnerability in a broad sense (Birkmann, 2005, 2006). The framework developed by Cardona and Barbat (2000) includes explicitly different scales of analysis and the interactions between them. Brooks (2003) developed a conceptual framework that may be applied consistently to studies of vulnerability and adaptation related to the impacts of climate variability and change within human systems. By distinguishing between social and biophysical vulnerability this approach aims at resolving the different formulations of vulnerability in the climate change literature. Schröter *et al.* (2005) propose a method to guide vulnerability assessments of coupled human–environment systems. It aims at informing the decision-making process about options for adapting to the effects of global change. The BBC framework, based on (Bogardi and Birkmann (2004) and Cardona, 1999a/b, 2001) incorporates the perspective of sustainable development into the assessment of vulnerability (Birkmann, 2006b). It distinguishes between the response before a disaster occurs (preparedness/risk reduction) and the response after (disaster emergency management). The BBC framework analysis vulnerability in a dynamic context and stresses the integration of the environmental dimension of vulnerability. It considers the links between communities and specific services and the vulnerability of ecosystem components to hazards (Renaud, 2006). Cutter *et al.* (2008a,b) describe the *Disaster Resilience of Place (DROP)* conceptual framework, conceived to improve comparative assessment of disaster resilience at the local or community level. It also includes a candidate set of variables for measuring resilience. Taking into account that the measurement of vulnerability is a challenge and using the more compatible approaches of the abovementioned frameworks (Cardona, 1999a, 2001; Cardona and Hurtado, 2000a/b; Cardona and Barbat, 2000; Turner *et al.,* 2003; IDEA, 2005; Birkmann, 2006b; Carreño *et al.,* 2007a/b) the MOVE project (Methods for Improvement of Vulnerability Assessment in Europe) have considered that vulnerability is related to the degree of *exposure*, *susceptibility/fragility and lack of resilience* of a socio-ecological system that favors adverse effects. Figure 2-1 describes this framework addressing vulnerability and disaster risk to natural and socio-natural hazards, emphasizing the association of risk assessment, risk management, adaptation and decisionmaking. It provides a summary of the causal and intervention aspects associated with this holistic vision of risk and vulnerability.

[INSERT FIGURE 2-1 HERE:
Figure 2-1. MOVE project framework on vulnerability and disaster risk assessment and management. Source: MOVE (2010).]

2.3.2. Interactions between Hazards and Society

The exposure is the social and material context represented by persons, resources, infrastructure, production, goods, services and ecosystems that may be affected by a hazard event. It is the inventory of components of society and environment that are exposed to the hazard from spatial and temporal point of view (Cardona 1986, 1990; UNISDR 2004, 2009b). If population and economic resources were not placed in potentially dangerous locations, no problem of disaster risk would exist. In fact land use and territorial planning are key factors in risk control and prevention. However, due to the intrinsically and fluctuating hazardous nature of the environment, increasing population growth, diverse demands for location and the gradual decrease in availability of safer lands, amongst other factors, it is almost inevitable that humans and human endeavour are many times located in potentially dangerous places. In fact, given that the same places are many times both endowed with natural resources and also periodically exposed to hazard (slopes, river flood plains, coasts, etc), location in hazardous areas is all but inevitable. Land use and territorial planning, or other forms of rationalizing location is, therefore, to reduce to a minimum unnecessary exposure and vulnerability to damaging events. Where exposure to events is impossible to avoid, land-use planning and location decisions must be accompanied by other structural or non structural methods for preventing or mitigating risk. Land use plans must be based on location and vulnerability reduction strategies and methods (UNISDR, 2009a). Migration, development models, regional commerce, economic dependency, global trends and transitions, among others, are also key issues related to exposure and physical susceptibility at local level.

Clearly the starting point for land use and territorial planning is knowledge of the natural environment, its resource and hazard base, the carrying capacity and limits to human usage, amongst other factors. At the same time, natural and basic sciences may provide information and knowledge as to the limits of the natural environment when faced with diverse humanly promoted land use options and processes and the potential for new humanly induced hazards- e.g. the degradation of aquifers due to urban development; increases in run off rates due to use of asphalt and concrete, and needed urban flood controls; possible local climate changes due to urban growth and the heat island effect.

From the perspective of the social sciences, location is the product of differing economic, social, cultural and political rationales where information on the physical base of the land, carrying capacity, limits to growth etc are ‘data’ or information filtered by social lenses and considered expeditiously or not according to convenience, social, economic and political calculation and needs, amongst other factors. The diversity of contexts to be found may be illustrated at an individual or family level examining two extremes (Lavell, 1999a, 2005).

Firstly, the economically well-off who conscientiously locate in areas known to be exposed to potentially very damaging event such as earthquakes and forest fires, due to the amenity value of these locations, and where they “reduce” risk through the use of safe building techniques, social protection mechanisms and insurance, for example. And, at the other extreme, poor families that locate in highly hazardous areas, due to the lack of access to the formal and more physically secure land market and where the risk of disaster is constantly traded off against the risk of every day life such that even where they are offered relocation they refuse to move due to the access they have to other survival resources *in locus*. Other sectors of society are located between these extremes and manage other location rationales.

From a governmental angle, although control of hazards should be an intrinsic part of governance rationales it is well known that the local, subnational, national and international scales in fact contribute enormously to unsafe location and increases in vulnerability. The granting of building permits in prohibited areas and the provision of basic urban services in areas highly exposed to hazards both serve to ‘institutionalize risk’ and in the end form part of what may be called ‘implicit’ urban policy. Under other circumstances and in other places governments strictly adhere to land use planning and hazard control location principles. Migration, development models, regional commerce, economic dependency, global trends and transitions, among others, are also key issues related to exposure and physical susceptibility at local level. Understanding this diversity of contexts and decisions is an intrinsic challenge for social science research.

As in the case of the study of socio-natural hazard processes, the relations between natural, basic, applied and social sciences in gaining an understanding of location, exposure and sensitivity may at times be one of sequenced inputs, the social interpretation of location and the search for control being based on a knowledge of the 'natural' limits to location and the ways in which human intervention can change the nature of the environment and the hazards it presents.

Seen from a more interactive stance it is once more with regard to research method, stakeholder participation and mechanisms for information and knowledge dissemination that more interaction between the sciences may be foreseen and planned for in understanding and intervening in location decisions. And, a lot of what information access is all about will inevitably pass through the filter of legal requisites and demands. Thus, one aspect of information generation and use is the way in which this is made available to collective or institutional primary decision makers (government and private sector, in particular). Another matter is with regard to the access to information afforded secondary, civil society and family level decision makers. Clearly the relations between social, natural, applied and basic science are fundamental in circumstances where social communication and democratic access to information are critical factors in helping reducing risk.

2.3.3. Vulnerability from a Social Viewpoint: Causal Factors

Understanding vulnerability requires an analysis of the contexts (physical, institutional, social, economic, etc.), characteristics and structure of human beings and their livelihoods that predispose them to such damage, loss and difficulties in recovery**.** Explanation of vulnerability constitutes a fundamental part of the definition of the notion and in this explanation varied aspects of a physical, technical, social and economic nature intervene, which require the presence and interaction of diverse sciences.

Vulnerability is the result of different social and environmental processes and the characteristics and conditions they give rise to. From a disaster risk perspective, it is a condition that exists with reference to a concrete hazard context and is, therefore 'determined', delimited or contextualized with reference to defined and delimited physical events. That is to say, a community is not vulnerable in general –although there are what could be called 'general vulnerability factors'–, but rather, vulnerable when faced with determined hazard conditions. Thus, vulnerability in relation to earthquakes is not necessarily the same as in relation to hurricanes, drought, or floods. Or, vulnerability used in reference to multi hazard contexts is not the same as in mono hazard exposure. This simple affirmation signifies that all vulnerability analyses or studies and all interventions to reduce or control vulnerability must be informed by a thorough understanding of the nature of the different potentially damaging physical factors that threaten different zones and populations.

Here one of the outstanding questions relates to the types, levels of sophistication, forms of expression and delimitation of the physical factors required for different types of vulnerability analysis and the methods used to get to this information, ranging from community based hazard and vulnerability analysis through to formal scientific research. Once again this signifies that the methods of generating and disseminating information amongst interest groups and stakeholders are as relevant a question and practice as is the generation of scientific information in itself. Information without communication is of little use where the final objective of research is social improvement and change.

Whilst accepting this general principle as to the hazard specific nature of vulnerability, it is also clear that certain factors, such as poverty, the lack of social networks and social support mechanisms, will aggravate or affect vulnerability levels irrespective of the type of hazard. This type of generic factor is different from the hazard-specific factors and assumes a different position in the intervention equation and the nature of risk management processes (ICSU-LAC, 2010).

Vulnerability of human settlements and ecosystems is intrinsically tied to different socio-cultural and environmental processes (Cutter ,1994; Kasperson *et al.,* 1988; Cutter *et al.,* 2008a,b). In any case it refers to susceptibilities or fragilities of the exposed elements; i.e. to the likelihood to be affected, but also it is related to the lack of resilience of the society and environment. Vulnerability is also closely tied environmental degradation (in both urban and rural contexts). This degradation may include local effects of global climate change.

When seen from a social viewpoint, vulnerability signifies a lack or deficit of sustainability. In this regard, risk is constructed socially, even though it has a relationship to physical and natural space. In many places, increases in vulnerability are likely to be related to factors such as rapid and uncontrollable urban growth and environmental deterioration. These lead to losses in the quality of life, the destruction of natural resources and landscape, and loss of genetic and cultural diversity. In order to analyse vulnerability as part of wider societal patterns it is necessary to identify the deep rooted and underlying causes of vulnerability and the mechanisms and dynamic processes that transform these into insecure conditions. All this leads to the conclusion that the underlying causes of vulnerability are social, economic, environmental, and political processes that affect the distribution of resources among different groups, which in turn reflect the distribution of power in society.

Some global processes are particularly significant drivers of risk. These include population growth, rapid urban development, international financial pressures, environmental degradation, and global warming. To take but a limited number of examples, urbanization processes have been an important factor in damage in urban areas; population increase helps to explain increases in the numbers of persons affected by floods and prolonged droughts; and deforestation increases the chances of flooding and landslides (Blaikie at al 1994; Glade, 2003; Wisner 2004, Bradshaw et al, 2007).

The causal factors of vulnerability have been defined as follows (Cardona, 1999a/b, 2001, 2010; Cardona and Barbat, 2000; Cardona and Hurtado, 2000a/b; Carreño *et al*., 2007a; McCarthy *et al.,* 2001; IPCC, 2007; ICSU-LAC, 2010, MOVE 2010):

- *Susceptibility* (*exposure*): physical predisposition of human beings, infrastructure and environment to be affected by a dangerous phenomenon due to its lack of resistance and location in the area of influence of the phenomenon.
- *Fragility* (*eco-social and economic*): predisposition of society and ecosystems to suffer harm resulting from the levels of fragility and disadvantageous conditions and relative weaknesses related to social, economic, ecological issues.
- *Lack of resilience* (*or ability to anticipate, cope and recover)*: limitations in access to and mobilization of the resources of the human beings and their institutions, and incapacity to adapt and respond in absorbing the socio-ecological and economic impact. The resilience includes the capacity to anticipate, cope and recover.

Several indicators or indices have been proposed to measure vulnerability from a comprehensive and multidisciplinary perspective. Their use intends to capture favourable conditions for direct physical impacts –such as exposure and susceptibility– as well as indirect and, at times, intangible impacts –such as socio-ecological fragilities and lack of resilience– of hazard events (IDEA, 2005; Cardona, 2006; Carreño *et al.,* 2007a). Therefore, according to this approach, exposure and physical susceptibility are necessarily ‘hard’ conditions for the existence of physical risk, or first order effects, and these are hazard dependent. The propensity to suffer negative impacts as a result of the socio-ecological fragilities and not being able to adequately face disasters, are circumstances of the context that can be considered ‘soft’ conditions, related to second order effects that aggravate the impact and usually are non-hazard dependent.

Vogel and O'Brien (2004) stress the fact that vulnerability is multi-dimensional and differential –i.e. varies across physical space and among and within social groups; scale-dependent with regard to time, space and units of analysis such as individual, household, region, system; and dynamic– characteristics and driving forces of vulnerability change over time (Leichenko and O’Brien, 2008). Especially the social dimension of vulnerability includes various themes such as social inequalities regarding income, age or gender, as well as characteristics of communities and the built environment, such as the level of urbanisation, growth rates, economic vitality, etc. (Cutter et al., 2003). However, although human society is the main focus of the concepts of vulnerability, some argue that human vulnerability can only be adequately characterised while simultaneously considering the vulnerability of the surrounding eco-sphere.

In summary, risk understanding depends on the understanding of how vulnerability can be captured in its different dimensions and spheres, and taking into account that vulnerability correlates with physical susceptibility (including the built environment), ecological fragility, social-cultural issues and socio-economic contexts. In addition, vulnerability is heavily influenced by the resilience; i.e. the adaptive ability of a socio-ecological system to absorb negative impacts as result of its capacity to anticipate, cope and recover quickly from damaging events. The lack of resilience means an important factor of vulnerability. In the framework of climate sensitivity resilience also means capacity of the system to learn about and adapt to a changing hazard situation. The promotion of resilient and adaptive societies requires a paradigm shift away from the primary focus on natural hazards and extreme weather events towards the identification, assessment and ranking of vulnerability (Maskrey 1993b; Birkmann 2006a/b).

2.4. Coping and Adaptive Capacities

Coping and adaptive capacity is an essential aspect of the ability to reduce risk. Most definitions of risk suggest that one major determinant of vulnerability is the lack of resilience or capacity, as described in Sections 2.2 and 2.3. In some frameworks, capacity is considered an important component of the reaction to an extreme event, and in others it is already taken into account when describing vulnerability to the event. Evidence indicates that capacity features in all stages of intervention of the 'disaster cycle or continuum': risk reduction and prevention, preparedness, response, recovery and reconstruction (Cardona et al, 2003; Lavell, 2005). Presence of capacity may suggest that impacts will be less extreme and/or the recovery time will be shorter, but high capacity to recover quickly –ex post– does not guarantee equal levels of capacity to anticipate –ex ante–. Regardless of where it is placed in the conceptual frameworks, capacity to cope and adapt are frequently seen as the target of policies and projects, which are based on the notion that strengthening capacity will lead to risk reduction. There is no consensus on whether capacity to cope and to adapt are the same, or by extension whether activities to build coping capacity are the same as those to build adaptive capacity. The two are often used interchangeably.

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This section discusses the role of capacity in risk reduction, introducing the different aspects of capacity, drivers and barriers of capacity and how to move from building to applying capacity. IPCC AR4 covered elements of adaptive capacity, options and constraints (Adger et al., 2007). This section expands the discussion by focusing on the role of capacity in exposure and vulnerability reduction, and by comparing coping and adaptive capacity, following Section 1.4. It includes a discussion on drivers and barriers of capacity, and concludes with ideas for moving from capacity to action on reducing risk.

This section discusses capacity in terms of coping and adaptive capacity, but acknowledges that very little scholarship talks explicitly about coping capacity, unless making an explicit distinction between coping and adaptive capacity. It is therefore not possible to make the assumption that every disasters-related mention of capacity describes what we define here as coping capacity. When capacity is discussed, it therefore refers to both or either adaptive and coping capacity, or else it is specified.

2.4.1. Capacity and Vulnerability

While the previous generation of risk studies focused on the hazards, recent reversal of this paradigm has placed equal focus on the vulnerability side of the equation (see Figure 2-1). Emphasising that risk can be reduced through vulnerability is an acknowledgement of the power of social, political, environmental and economic factors in driving risk. While these factors drive risk on one hand, they can on the other hand be the source of capacity to reduce it (Carreño et al 2007a; Gaillard, 2010). This section addresses different treatments of the relationship between capacity and vulnerability, in order to identify the dimensions of capacity and how it relates to climate change and disaster risk. It is important to recognise that 'capacity' is used liberally in the contexts of both climate change and disaster risk, but this section refers only to coping and adaptive capacity, which respectively refer to the ability to cope and adapt in the face of risk.

Much risk reduction work uses existing capacity as a baseline for understanding how vulnerable people are to a specific hazard. The relationship between capacity and vulnerability is described differently among different schools of thought, stemming from different uses in the fields of development, disaster risk management and climate change adaptation. Gaillard (2010: 223) notes that the concepts capacity, vulnerability as well as resilience 'played a pivotal role in the progressive emergence of the vulnerability paradigm within the scientific realm'. Roughly, the literature describes the relationship between vulnerability and capacity in three ways, which are not mutually exclusive (Brooks et al, 2005; Yomani, 2001; Moss et al 2001; IPCC TAR, 2001; Smit and Wandel, 2006):

1) Vulnerability is the result of a lack of capacity
2) Vulnerability is the opposite of capacity
3) Capacity is one element of vulnerability.

The difference can be seen in the variations of the conceptual equation Risk = Hazard x Vulnerability (e.g. Blaikie et al., 1994), where capacity is either left out, assumed to already have been 'subtracted' from vulnerability, or included, as in the versions Risk = (Hazard x Vulnerability)/Capacity or Risk = Hazard + Vulnerability – Capacity. Similarly, building capacity is seen as the means for vulnerability reduction (Downing and Patwardhan, 2004; Gaillard, 2010). Resilience also plays a role in the discussion on capacity and vulnerability (Cardona 2001, Birkmann, 2006a). Resilience is also seen as the opposite of vulnerability (Gaillard, 2010), making the distinction between capacity and resilience necessary, although this distinction can be hard to delineate in reality. Some say that resilience includes coping capacity but at the same time goes beyond it (Cardona 2004, 2010; IDEA 2005, Thywissen, 2006). Timmerman (1981) defines resilience as the capacity of a system to absorb and recover from the occurrence of a hazardous event. Cutter et al (2008) describe this as 'absorptive capacity'.

Although there is a difference between coping and adaptive capacity (see below), coping capacity can be considered a part of adaptive capacity. Figure 2-2 shows how vulnerability, resilience and adaptive capacity have been related to each other differently in the global environmental change and hazards fields. Cutter et al (2008) review perspectives in global environmental change work that place (A) resilience as a part of adaptive capacity, (B) adaptive capacity as a part of vulnerability or (C) nests them as part of an overall framework of vulnerability. From the hazards perspective, they note views where (D) resilience as the ability to bounce back is a part of vulnerability, (E) adaptive capacity is seen as part of resilience, or (F) vulnerability and resilience as separate but related concepts (Cutter et al, 2008).

[INSERT FIGURE 2-2 HERE:
Figure 2-2. Conceptual framework relating adaptive capacity, resilience and vulnerability in the global environmental change and hazards communities of practice. Source: Cutter et al. (2008).]

The relationship between capacity and vulnerability is interpreted differently in the climate change community of practice and the disaster risk management community of practice. There is a history of examining vulnerability and capacity in humanitarian work, which has contributed the Vulnerability and Capacity Analysis/Assessment approach (VCA) (Davis et al, 2004), which uses a variety of development-focused field methodologies. This approach stems from the original work by Anderson and Woodrow (1989, second edition 1998). The purpose of these assessments is to 'provide analytical data to support better informed decisions on the planning and implementation of risk reduction measures' (Davis et al, 2004). Weighing vulnerability and capacity against each other has not always been part of the process of response and recovery, however. Anderson and Woodrow pointed to a lack of understanding of how processes of response and recovery following disasters contributed to vulnerability. Throughout the 1980s vulnerability became a central focus of much work on disasters, in some circles overshadowing the role played by hazards in driving risk. Some have noted that the overt emphasis on vulnerability tended to ignore capacity, focusing too much on the negative aspects of vulnerability (Davis et al, 2004). Recognising the role of capacity in reducing risk also indicates an acknowledgement that people are not 'helpless victims' (Gaillard, 2010: 222).

In the climate change approach, capacity was also initially subsumed under vulnerability. The first handbooks and guidelines for adaptation emphasised impacts and vulnerability assessment as the necessary steps for determining adaptation options (Feenstra *et al.,* 1998; Kates *et al.,* 1985; Carter *et al.,* 1994; Benioff *et al.,* 1996). This can be understood in that climate change vulnerability was often placed in direct opposition to capacity. As a result, vulnerability that was measured was seen as the remainder after capacity had been taken into account.

Gaillard (2010) suggests that one difference between capacity and vulnerability that makes them difficult to juxtapose, is that capacity is often rooted in endogenous resources and relies on traditional knowledge, indigenous skills and technologies and solidarity networks, whereas vulnerability depends on exogenous structural constraints.

Although extensive theoretical scholarship discusses the links between capacity, vulnerability and resilience, in reality it can be unclear. Nelson and Finan (2009) describe a case in northeast Brazil where the public actions related to drought mitigation have on the one hand reduced the vulnerability of rainfed farmers to some adverse effects of drought by providing safety nets and other relief programmes, but this has resulted in a reduction in resilience of the social-ecological rainfed farming system. Davis *et al.* (2004), IDEA (2005), Carreño *et al.* (2007a/b) and Gaillard (2010) note that capacity and vulnerability should not be positioned as opposites because communities that are highly vulnerable may in fact display high capacity in certain aspects. This reflects the many elements of risk reduction and the multiple capacity needs across them. Alwang *et al.* (2001: 18) also underscore that vulnerability is dynamic and determined by numerous factors, thus high capacity in the ability to respond to an extreme event does not accurately reflect vulnerability.

Interestingly, coping and adaptive capacity both feature in the definition of vulnerability in the IPCC AR4, specifically that vulnerability is defined as the degree to which a system is unable to cope with adverse effects of climate change, including climate variability and extremes and is a function of a system's adaptive capacity. This approach suggests that with respect vulnerability, coping capacity is a measure of how likely a system is to be affected, and –the lack of– adaptive capacity is a determinant of vulnerability.

As set out in Section 1.4, there is a difference in understanding and use of the terms coping and adapting. In some cases, the two are considered synonyms or coping capacity is considered a subset of adaptive capacity (Patterson et al, 2010), whereas in other cases the distinction between them is considered large. In the latter case, a number of conceptual and practical differences are highlighted. Here we draw on some of these distinctions to discuss differences between coping and adaptive capacity.

Although coping capacity is often used interchangeably with adaptive capacity in the climate change literature, Cutter et al (2008) point out that adaptive capacity is more likely to feature in global environmental change perspectives and is less prevalent in the hazards discourse where the term 'mitigation' is used instead.

Adaptive capacity refers to the ability of a system to adapt to climate change, but it can also be used in the context of disaster risk. Because adaptive capacity is considered to determine 'the ability of an individual, family, community or other social group to adjust to changes in the environment guaranteeing survival and sustainability' (Lavell, 1999b: 8), many believe that in the context of uncertain environmental changes, adaptive capacity will be of key significance. Dayton-Johnson (2004) defines adaptive capacity as the 'vulnerability of a society before disaster strikes and its resilience after the fact'. The IPCC AR4 defined it as 'the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (Parry et al, 2007). Some ways of classifying adaptive capacity include 'baseline adaptive capacity' (Dore and Etkin, 2003), which refers to the capacity that allows countries to adapt to existing climate variability, and 'socially optimal adaptive capacity', which is determined by the norms and rules in individual locations (Dore and Etkin, 2003). Another definition of adaptive capacity is the 'property of a system to adjust its characteristics or behaviour, in order to expand its coping range under existing climate variability, or future climate conditions' (Brooks and Adger, 2004). This links adaptive capacity to coping capacity, because coping range is synonymous with coping capacity, referring to the boundaries of systems' ability to cope (Yohe and Tol, 2002).

In simple terms, coping capacity refers to the 'ability of people, organisations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters' (UNISDR, 2009b). Coping capacity is typically used in humanitarian discourse to indicate the extent to which a system can survive the impacts of an extreme event. It suggests that people can deal with some degree of destabilisation, and acknowledges that at a certain point this capacity may be exceeded. Eriksen et al (2005) link coping capacity to entitlements – the set of commodity bundles that can be commanded – during an adverse event. The ability to mobilise this capacity in an emergency is the manifestation of coping strategies (Gaillard, 2010).

The capacity described by the disasters community in the past decades does not frequently distinguish between ‘coping’ or ‘adaptive’ capacities, and instead the term is used to indicate positive characteristics or circumstances that could be seen to offset vulnerability. Because the approach is focused on disasters, it has been associated with the immediate-term coping needs, and contrasts from the long-term perspective generally discussed in the context of climate change, where the aim is to adapt to changes. There has been considerable discussion throughout the vulnerability and poverty and climate change scholarly communities about whether coping strategies are a stepping stone toward adaptation, or toward maladaptation (Eriksen et al, 2005; Yohe and Tol, 2002) (see Chapter 1). This can also be applied in the context of capacity. Useful alternative terminology is to talk about capacity to change and adjust (Nelson and Finan, 2009) for adaptive capacity and capacity to absorb instead of coping capacity (Cutter et al, 2008).

In the climate change community of practice, adaptive capacity has been at the forefront of thinking regarding how to respond to the impacts of climate change, but it was initially seen as a characteristic to build interventions on, and only later has been recognised as the target of interventions (Adger et al, 2004). The UNFCCC, for instance, states in its ultimate objective that action to reduce greenhouse gas emissions be guided by the time needed for ecosystems to adapt naturally to the impacts of climate change. This suggests an implicit notion that the limits for emissions are to be guided by the limits to natural adaptive capacity. Consequently, adaptive capacity has been a central issue in the climate change policy debates since their inception, although the IPCC TAR noted that scholarship on adaptive capacity was at the time ‘extremely limited in the climate change field’ (Smit et al, 2001: 895).

Regardless of what it has been called, it is now recognised that there are different elements of the disaster continuum that all require different capacities. These capacity needs are discussed in the following section.

2.4.2. Different Capacity Needs

Capacity can be seen from two perspectives: existing capacity and missing capacity. At its core, risk reduction initiatives aim either to use existing adaptive capacity as a baseline, or to build it up if it does not exist or is inadequate. However, this is an oversimplification of the dimensions of capacity. Capacity to anticipate a disaster requires a different set of skills, networks, and capitals than capacity to respond to and recover from a disaster (Lavell, 1994; Lavell and Franco, 1996; Cardona, 2001, 2010; Carreño et al, 2007a/b; ICSU-LAC, 2010; MOVE 2010).

Just like vulnerability and resilience, capacity is dynamic and will change over time. Cutter et al (2008) and Marulanda et al (2008b, 2009, 2010) point out how capacity diminishes in situations were communities have to cope with recurrent hazards, because dealing with one event takes away assets that make people not only more vulnerable to the next event, but also reduce their capacity to absorb and recover from the event.

The discussion in Section 2.4.1 indicates that there are differing perspectives on how coping and adaptive capacity relate. When coping and adapting are viewed as different, it follows that the capacity needs for each are also different (Cooper et al, 2008). This section discusses different capacity needs in the different stages of the disaster cycle: anticipation, response, and recovery.

There are different dimensions of capacity that recur in the literature, including the location, timing, and the actors involved. Capacity varies from place to place, and also has a temporal component (Yohe and Tol, 2002). Capacity determinants vary across systems, sectors and regions and between developed and developing countries (McCarthy et al, 2001) as well as within countries (Kates, 2000). There is also indication that a local focus is more appropriate than a macro-scale focus (Smit and Wandel, 2006). One of the advantages of local assessments of capacity is the ability to reflect differences on a local scale.

The scale also has implications for the unit of analysis. It is therefore relevant to ask whose capacity is in focus. Communities are considered a vital action space for building capacity (Yodmani, 2001; Gaillard, 2010; Van Aalst et al, 2008), and are often a unit of analysis for capacity assessment (Patterson et al, 2010). There is some discussion about the extent to which this reflects differential needs, vulnerabilities and capacities however. Yodmani (2001) notes that involvement of communities in building capacity facilitates appropriate interventions, however in a community context, individuals can be limited in their capacity due to institutional and policy structures over which they have little power (Patterson et al, 2010). Brooks et al (2005) instead suggest a focus on national level adaptive capacity, as an appropriate scale for policy formulation.

Capacity to cope depends on assets, opportunities, social networks, local and external institutions, as well as people's perceptions of their capacity. Responses to hazards are determined by a conceptual understanding of the reason for the hazards; for some this means more prayers, for others it means being better prepared. An expanding body of knowledge on the role of culture in influencing how people perceive and respond to risk underscores the importance of including these dimensions in the entire cycle of disaster response-recovery and adaptation (Kellman et al, 2009; Dekens, 2007a and 2007b; Schipper, 2010; Gaillard, 2010; O'Brien; Wolf et al; Adger et al). Perception and beliefs also determine how vulnerable people categorise themselves (e.g. Klein, 2009; etc).

General requirements for capacity are access to resources and entitlements (Gaillard, 2010), as well as livelihood diversity (Yodmani, 2001). Brooks et al (2005) underscore the importance of the temporal dimension. Needs change over time and throughout the disaster cycle. The following sections discuss capacity needs at different stages in the disaster continuum.

2.4.2.1. Capacity to Anticipate

Disasters are defined by their ability to overwhelm people's immediate capacities to cope (Anderson and Woodrow, 1998). Strengthening capacity to anticipate disasters is a key *ex ante* way to ensure that these events do not engulf people's ability to manage and do not leave them significantly worse off after. Anticipating disasters involves warning and preparedness but goes beyond it to include ensuring other *ex ante* actions such as risk prevention and reduction; i.e. daily decisions and actions to minimise both vulnerability and exposure to hazard events. Development planning, including land-use and urban planning, hydrologic basin and territorial ordering, hazard-resistant building codes enforcement and landscape design are all activities that can reduce exposure and vulnerability to hazards (Cardona, 2001, 2010). All play a role in disaster anticipation, and the ability to carry these out in an effective and risk reduction way will enhance anticipatory capacity. Capacity to anticipate also requires diversifying income sources, maintaining social networks, taking collective action to avoid development plans that put people at higher risk (Maskrey, 1989, 1994b; Lavell, 1994, 1999b, 2005). Successful anticipation relies on all of these components, some of which will be more important depending on the circumstances.

Anticipatory capacity also depends on capacity to prepare for a disaster. This is a form of risk management that differs from anticipatory risk prevention and reduction. Preparedness includes prevision, monitoring of hazards and dissemination of information and warnings (including early warning), having emergency plans and accessible evacuation information (including maps, shelters, emergency supplies). The 2004 Indian Ocean tsunami highlighted the importance of early warning systems. There are still regions in the world (e.g. the Mediterranean) that don't have early warning systems. The Indian Ocean early warning system was recently established but is not yet fully functional in every member country and as a fully integrated system. Building early warning systems is a complex process, both technically and socially. To date, far more effort has focused on getting the technology done, very little has been done to understand human aspects and to enable the positioning of early warning systems in different cultural contexts (Cardona, 1996b; Thomalla et al., 2009 and forthcoming). Particularly important here are different risk perceptions arising from different values and beliefs. Long-term support is needed to build the capacity of sub-national institutions to develop, implement, maintain and improve early warning systems (Cardona, 1996b; Thomalla et al., 2009 and forthcoming). Cannon (2008) notes that there are limits to the sort of preparedness that can be taken on the local level. Citing the storm shelters in Bangladesh, he notes that this type of investment is not feasible for the household of village level.

Even where disaster has not yet materialized, risk and risk factors are always present and may be the subject of conscious human modification, reduction or control. Risk prevention and reduction may be understood as a series of elements, measures and tools directed towards intervention in hazards and vulnerabilities with the objective of reducing existing or controlling future possible risks (Cardona et al, 2003). This concept of anticipation can be differentiated from another group of tools whose objective has been the improvement of intervention in disasters once these occur: response and recover (Cardona el at, 2003; Lavell, 2005).

Up to the beginning of the 1990s, disaster preparedness and humanitarian response dominated disaster practice. Risk reduction (corrective and prospective) was not a priority for public policy or in terms of social action in general. However, in the face of growing evidence as to significant increases in disaster losses and the inevitable increase in financial and human resources dedicated to disaster response and recovery have been increasing recognition of the need to promote prevention and risk reduction over time (Lavell 1994, 1999b, 2005). Notwithstanding, different actors, stakeholders and interests influence the capacity to anticipate a disaster. Actions to minimise exposure and vulnerability of one group of people may come at the cost of increasing it for another.

2.4.2.2. Capacity to Respond

The response phase is during and immediately after an extreme event. Response capacity helps people cope in this period. Responding spans everything from people's own initial reactions to a hazard upon its impact to the phase immediately following, which is typically characterised by the external assistance. Capacity to respond can thus be broken down into sub-components that describe the internal or inherent capacity as well as the external capacity that comes in the form of relief assistance through medial attention and supplies, and food as well as volunteers, shelter and other urgent supplies.

Recurring disasters break down the drivers of coping capacity, increasing vulnerability to hazards (Wisner and Adams, 2003; Marulanda et al, 2008b, 2009, 2010; United Nations, 2009). Unprecedented hazards may also overwhelm existing coping capacity. External emergency assistance following a disaster buffers existing coping capacity (REF), but may also be eroded in event of frequent, recurring hazards. Internal and external capacity are not unrelated. External assistance may have adverse consequences on internal capacity in the short, medium and long term (Anderson and Woodrow, 1989). When emergency response is not in line with development priorities, it is likely to leave people worse off than before, reversing decades of development (DfID, 2004; Anderson and Woodrow, 1989; 1991).

The emergency response phase is when the greatest amount of resources are available, most commonly through humanitarian assistance (REF). While some consider this process necessary, it is also disruptive, often leaving people in temporary shelters for extended periods. Humanitarian operations are complex in themselves, with lack of co-ordination among external agencies, between external agencies and local authorities, between external agencies and local people and community based organizations, etc., and issues such as abuse of refugees, corruption (Bailey, 2008; Transparency International, 2010). It has been suggested that the disruption caused by relief operations can in some cases be worse than the disruption caused by a disaster, as embodied in the phrase: 'First the earthquake, then the disaster' (Oliver-Smith, 1999: 86).

Humanitarian aid and relief interventions have also been discussed in the context of their role in reinforcing or even amplifying existing vulnerabilities (Anderson and Woodrow, 1991, 1998; Wisner, 2001a; Schipper and Pelling, 2005; various gender refs). The direct conflict between humanitarian aid and development has also been highlighted (Bull-Kamanga et al., 1999). Evidence for these observations can be found extensively in the field. It has been noted that sustainable food security is threatened by certain short-term interventions, such as food-for-work programmes, which are considered by some to be medium-term solutions. In some cases, outside relief in the form of food aid has gone from short-term, temporary emergency relief to long-term, continuous donations. This is the case for Ethiopia, a country that has received food aid since an initial damaging drought in 1974 and now has an adult generation that has been entirely nourished on aid food.

There is a considerable literature assessing the success of relief programmes such as food-for-work and similar safety net programmes that have been implemented for instance in Ethiopia (Lind and Jalleta, 2005). This literature focuses on the role of these programmes vis-à-vis bringing people out of poverty. In particular, the discussion centres on how to approach chronic vs. transient vulnerability/poverty. Chronic vulnerability suggests that people are inherently vulnerable to natural hazards, whereas transient vulnerability means that people are likely to recover from their temporary loss of coping capacity. This approach suggests that there are both larger, underlying drivers of vulnerability, such as those described by Wisner et al. (2004) as well as temporary factors that create transient states of vulnerability. Compound emergencies/complex emergencies/compound events, such as when natural hazards hit during a war, or when a storm occurs at the same time as an earthquake, shift people to a different dimension of vulnerability.

Wisner (2001a) shows how poorly constructed shelters where people were placed temporarily in El Salvador following 1998 Hurricane Mitch turned into ‘permanent’ housing when NGO support ran out. When two strong earthquakes hit in January and February 2001, the shelters collapsed, leaving the people homeless again. This example illustrates the perils associated with emergency measures that focus only on the relief phase, and do not take the recovery phase into account.

There is substantial debate on the role played by migration in adaptation, and whether the ability to migrate demonstrates adaptive capacity (EACH-FOR, 2007). A global research effort to understand whether the concept of environmental change-induced migration exists in reality showed many surprising results, including that migration is already part of the adaptive repertoire of many people, and that a significant amount of capacity is needed in order to migrate.

2.4.2.3. Capacity to Recover

Capacity to recover is not only dependent on the extent of a physical impact, but also on the ability to resume livelihood activities (Hutton and Haque, 2003) and return to previous levels of development or better. The phrase ‘building back better’ reflects the acknowledgement that reconstruction processes that aim to return to ‘normalcy’ often are out of synch with the evolving process of development (Mitchell, 2008). Because reconstruction processes often do not take people’s livelihoods into account, instead focusing on their safety, new settlements are often located where people do not want to be. Innumerable examples indicate how people who have been resettled return back to their original location, moving into dilapidated houses or setting up new housing (even if more solid housing is available elsewhere, e.g, El Salvador after Mitch) simply because the new location does not allow them easy access to their fields (for farmers), to markets or roads, to the sea (e.g. Sri Lanka after the tsunami). There are also social reasons why people return to the same location, even if they aware of the risks. The poorer people become, the more likely that risk has lower priority than the threats of homelessness, lack of employment, illness and hunger (Huttan and Haque, 2003; Maskrey, 1994b).

The recovery and reconstruction phases after a disaster provide an opportunity to rethink previous conditions and address the root causes of risk, looking to avoiding reconstruct the vulnerability (IDB, 2007), but often the process is too rushed to enable effective reflection, discussion and consensus building (Christoplos, 2006). Several examples have shown that capacity to recover is severely limited by poverty (Chambers, 1983; Ingham, 1993; Hutton and Haque, 2003), where people are driven further down the poverty spiral, never returning to their previous conditions.

There are few studies looking at how the process of recovery from large disasters relates to adaptation to climate change (Christoplos et al., 2010; Thomalla et al, 2009) but it has been acknowledged that important lessons can be drawn for understanding how to build adaptive capacity (Pelling and Schipper, 2009). The study examining 10 years after Hurricane Mitch in Nicaragua indicated that an evolution of rhetoric from risk management terminology to climate change terminology was not accompanied by a shift in attitude and emphasis from response-focused activities toward preparedness (Christoplos et al, 2010).

Lessons learned from studying the 2004 Indian Ocean tsumani (Thomalla et al, 2009; Thomalla et al, forthcoming) suggest that:

- Social vulnerability to multiple hazards, particularly rare extreme events tends to be poorly understood. Many vulnerability and capacity assessments (both by NGOs and academics) are poorly conducted and don’t identify and address the complexity of causes and drivers of vulnerability.
- There is an increasing focus away from vulnerability assessment towards resilience building. However,

resilience is poorly understood and a lot needs to be done to go from theory to practice. Questions include: What are appropriate levels, characteristics and indicators of resilience, and how can we monitor and evaluate whether we are successful in building resilience? How can resilience be built without understanding vulnerabilities?

- One of the key issues in sub-national disaster risk reduction initiatives is a need to better define the roles and responsibilities of government and NGO actors and to improve coordination between them. Without mechanisms for joint target setting, coordination, monitoring and evaluation, there is much duplication of efforts, competition and tension between actors.
- Disaster risk reduction is only meaningful and prioritised by local government authorities if it is perceived to be relevant in the context of other, more pressing day-to-day issues, such as poverty reduction, livelihood improvement, natural resource management, and community development. Projects that demonstrate these linkages and emphasise win-win outcomes are likely to be more successful at the local level.

2.4.3. Factors of Capacity: Drivers and Barriers

Since the TAR recognised the dearth of scholarship on adaptive capacity (Smit et al, 2001), much effort has gone into developing knowledge on what constitutes adaptive capacity and how it can be built (Adger et al, 2004).

Early work points to factors of capacity such as: an integrated economy; urbanisation; information technology; attention to human rights; agricultural capacity; strong international institutions; access to insurance; and class structure (Handmer et al, 1999; Cannon, 1994). Others identify life expectancy; degree of urbanisation; access to public health facilities; community organisations; existing planning regulations at national and local levels; institutional and decision-making frameworks; existing warning and protection from natural hazards; functioning government; and health and well-being (Klein, 2001; Brooks et al, 2005; Barnett, 2005). Although they acknowledge that adaptive capacity is not only a factor of wealth, Ahmed and Ahmad underscore the importance of provision of resources for enhancing ‘the capacity and endurance of the affected people to cope with adversities’ (2000: 100).

As a way of understanding adaptive capacity further, numerous scholars have developed indicator systems. These are used both to measure adaptive capacity as well as to identify entry points for enhancing the capacity (Adger and Vincent, 2005; Eriksen and Kelly, 2007; Downing et al, 2001; Brooks et al 2005; Lioubimtseva and Henebry, 2009; Swanson et al., 2007).

Indicators can be a useful starting point for a discussion on what qualifies as an appropriate proxy for capacity, in order to determine what sort of factors act as barriers and drivers. When rooted in the poverty and livelihoods discourse on vulnerability (Chambers, 1989; Swift, 1989), proxies for capacity look very similar to indicators of development, despite the significant argument about the causal structure of vulnerability, which underscores that vulnerability is not the same as poverty (Chambers, 1989; Ribot, 1996). It may be tempting to suggest that any driver of development is also a driver of vulnerability, however there is not always empirical evidence about how the factors actually affect adaptive capacity. It may instead be easier to identify the barriers to adaptive capacity.

Lopez-Marrero (2010) says that an integrated approach taking into account resources as well as the cognitive aspects of adaptive capacity is necessary, but little research has been on cognitive determinants and factors that influence action.

Access to and the availability of resources is considered to be the major factor for adaptive capacity (Brouwer et al. 2007; Ford et al. 2008; Pelling 1997; Reid et al. 2007), but there are other aspects as well: cultural norms, the availability of information and the role of scientific information in decisionmaking, and political feasibility.

Although economic resources are not the only limit to building capacity, they are still important. Corruption is considered a taboo subject (Transparency International) but plays a part in translating how financial resources affect capacity.

Barriers and drivers of adaptive capacity are location specific.

2.4.4. From Capacity to Action

Although there are no real examples of long-term processes of adaptation to anthropogenic climate change, there is history of adaptation taking place across time and space (Adger and Brooks, 2003). There is limited knowledge on how to move from what is considered sufficient adaptive capacity to ensuring that adaptation takes place. What needs to be done to move from capacity to action? Mortimore (2010: 135) suggests that local adaptive capacity is a ‘platform for constructing enabling development policies’. Eakin and Lemos (2010) also note the limited empirical research on how institutions affect adaptive capacity and shape the means to build it further.

2.5. Dimensions of Exposure and Vulnerability

This section presents some of the major dimensions of exposure and vulnerability in relation to, variously, hazards, disasters, climate change and extreme events, which represent distinct scholarly communities. Their definitions and applications of the, sometimes confounded, terms exposure and vulnerability, although quite specific to them, together contribute to a very broad range of dimensions which some have sought to integrate (e.g. Füssel, 2005). The largest body of evidence refers to vulnerability rather than exposure and the distinction is often not made explicit.

O’Brien *et al*. (2008) recognize the complex interactions of biophysical, social, economic, political, institutional, technological and cultural conditions as constitutive of a general ‘social vulnerability’ approach (2008: 13). This they contrast with a hazard-centred, ‘physical vulnerability’ approach emphasizing the bio-geo-physical and technological interpretations of vulnerability. The former focuses chiefly on physical processes of exposure and vulnerability creation and reduction through e.g. engineering and technological interventions. The latter approach goes beyond this to include also the complex, societal, root causes of vulnerability to climate change and extreme events, which require similarly complex societal responses for their reduction.

The social dimension of vulnerability includes various themes such as social inequalities regarding income, age or gender, as well as characteristics of communities and the built environment, such as the level of urbanisation, growth rates, economic vitality, etc. (Cutter *at al.,* 2000). Although human society is the main focus of the concepts of vulnerability, a fundamental question has to be clarified as to whether human vulnerability can be adequately characterised without considering simultaneously the vulnerability of the “surrounding” eco-sphere. Vogel and O'Brien (2004) stress the fact that vulnerability is *multi-dimensional and differential* – i.e. varies across physical space and among and within social groups; is *scale-dependent* with regard to time, space and units of analysis such as individual, household, region, system; and *dynamic* – characteristics and driving forces of vulnerability change over time.

At present, comprehensive or integrated approaches for vulnerability and risk understanding consider different dimensions or aspects of vulnerability as proposed by Wilches-Chaux (1989). These dimensions are correlated to human security components and include physical, environmental, economic, social, political, institutional, educational, cultural, and ideological dimensions. This deconstructive approach helps us visualize vulnerability from different angles and perspectives that involve also technological, anthropological and psychological aspects. This facilitates an understanding of vulnerability as a dynamic and changing circumstance or condition.

In identifying the dimensions of exposure and vulnerability, the literature (and the definitions) can cross certain conceptual boundaries. For example, the answer to the question, “vulnerable to what?” can refer to an external hazard or threat or to the outcome. Dilley and Boudreau (2001) identify this as a particular problem in food-related contexts where the typical answer might be, vulnerable to “famine”, “food insecurity”, or “hunger”, which are adverse outcomes rather than the precipitating events or shocks.

Out of the many possible vulnerabilities Schneider *et al.* (2007) recognize "key vulnerabilities" associated with many climate-sensitive systems, such as "food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation." (Schneider *et al.,* 2007: 781). A temporal dimension –i.e. whether the vulnerability is likely to be realized sooner rather than later– is an important element in determining whether a vulnerability dimension can be termed "key" (Bazerman, 2005; Schneider *et al.,* 2007: 785).

This section aims to be reasonably comprehensive without being exhaustive and combines both 'social vulnerability' and 'physical vulnerability' approaches. The discussion is organized under the following main headings (with important sub-headings):

- Physical
- Environmental
- Economic
- Social
- Cultural
- Institutional and governance

In practice, vulnerability in its realization will be a composite of two or more of these main dimensions. An additional subsection discusses interactions and integrations. Finally, there are issues related to timing and timescales, as well as spatial and functional scales.

2.5.1 Physical Dimensions

The physical dimension of vulnerability begins with the recognition of a link between an extreme physical or natural phenomenon and a vulnerable human group (Westgate and O'Keefe, 1976). It comprises aspects of geography, location, place (Wilbanks, 2003); settlement patterns; and physical structures (Shah, 1995; UNISDR, 2004):

> *"Physical exposure of human beings and the fragility of economic assets to disasters have been partly shaped by patterns of settlement. Beneficial climatic and soil conditions that have spurred economic activities are associated with hazard-prone landscapes. Both volcanic slopes and flood plains historically have attracted human activities." (UNISDR 2004).*

However, physical vulnerability also encompasses the non-human/social. It also refers to infrastructure or environmental elements located in hazard prone areas or with deficiencies in resistance or susceptibility to damage (Wilches-Chaux 1989). It,can include vulnerable *systems* such as low-lying islands, coastal zones, mountain regions, drylands, and islands identified as Local Agenda 21 priorities (UNCED, 1992; Dow 1992: 420); also *impacts* to these systems (e.g. flooding of coastal cities and agricultural lands or forced migration); and/or the *mechanisms* causing these impacts (e.g. disintegration of particular ice sheets) (Schneider *et al.,* 2007: 783; Füssel and Klein, 2006).

2.5.1.1. Geography, Location, Place

There are very different vulnerabilities in different world regions. Broadly speaking, developing countries are recognized as facing the greater impacts and having the most vulnerable populations, least able to easily adapt to changes in *inter alia* temperature, water resources, agricultural production, human health and biodiversity (McCarthy *et al.,* 2001; IPCC, 2001; Beg *et al.,* 2002). This is of course a simplification (and see Bankoff 2001: 19 for a critique of essentialising, cultural discourses which malign large parts of the world as "disease-ridden, poverty-stricken and disaster-prone") but does distinguish the distributional aspects of climate change. Dilley *et al.* (2005) have identified 'disaster hotspots' by combining hazard exposure with historical vulnerability to categorize a geographical distribution of hazards –areas that are at relatively higher single– or multiple-hazard risk –at the sub-national scale.

Also vulnerable are threatened systems confined to narrow geographical ranges (McCarthy *et al.,* 2001) and, less clearly delineated, trade corridors (link to the *economic* dimension below) which are extended, cross boundary regions vulnerable to extreme events. Temperature and precipitation changes arising from climate change can be expected to have both positive and negative impacts around the world. Such changes may reduce the growing period that would in turn affect agricultural zones in many parts of the world albeit this must then take account of mitigation and adaptation actions, which could affect vulnerability status (see below Section 2.5). Downing (1991) discusses just such a scenario but goes further by extending the dimensions of vulnerability to 'vulnerability to hunger' in an African context.

Highly vulnerable locations include small island developing states (SIDS) because of the proportion of their land mass which is exposed to rising sea levels or storms (UNISDR 2004; Nichols 2004; Pelling and Uitto 2001). But the most biophysically vulnerable locations may not always intersect with the most vulnerable populations (Cutter *et al.,* 2000).

The physical dimension refers to a location-specific context for human–environment interaction (Smithers and Smit 1997, 131 that should also recognize that vulnerability is manifested at a specific point in space and time and is "a product of various processes operating at various geographic levels. Processes may converge differently at different points in space or time, creating a very different manifestation of vulnerability" (Eriksen, Brown and Kelly, 2005). Furthermore, Cutter's (1996) 'hazards of place' model of vulnerability expressly refers to the temporal dimension (see below) which argues for a more nuanced approach recognizing the dynamic nature of place vulnerability.

2.5.1.2. Settlement Patterns and Development Trajectories

There are specific vulnerability dimensions to do with urbanization (Hardoy and Gustavo Pandiella 2009) and rurality (Nelson *et al.,* 2010a, 2010b).

Rapid urbanization has been shown to be vulnerable to disaster risk (Sánchez-Rodríguez *et al.,* 2005) and especially the development of megacities with high population densities (Mitchell, 1999a, 1999b) leading to greater numbers exposed and increased vulnerability through, inter alia, poor infrastructural development Uitto 1998). Mitchell (1999b) identifies increased polarization and spatial segregation of groups with different degrees of vulnerability to disaster as an emerging problem. This is supported by Cutter and Finch's (2008) empirical evidence from the USA (between 1960 and 2008) of the spatial patterning of social vulnerability. Those components that consistently increased social vulnerability were density (urbanization), race/ethnicity (see below) and socioeconomic status. The level of development of the built environment, age, race/ethnicity, and gender, account for nearly half of the variability in social vulnerability among U.S. counties in their Social Vulnerability Index (SoVI). The study found considerable regional variability and that social vulnerability had become more dispersed.

The built environment can be either protective of, or subject to, climate extremes. It is both vulnerability perpetrator and victim. Inadequate structures make victims of their occupants and conversely, adequate structures can reduce human vulnerability. The continuing toll of deaths and injuries in unsafe schools (UNISDR, 2009a), hospitals and health facilities (PAHO/World Bank, 2004), domestic structures (Hewitt, 1997), lifelines and critical infrastructure () and infrastructure more broadly (Freeman and Warner 2001) are indicative of the vulnerability of many parts of the built environment and the creation of a 'social geography of harm' (Hewitt, 1997). The deaths and injuries of children in their schools is a dereliction of a collective duty of care given the technical abilities worldwide to build such structures safely (UNISDR, 2007c). Reducing the vulnerability of hospitals and other health care facilities protects the safety of patients, staff and visitors, as well as the investment in infrastructure, and ensures the continuance of health response when disasters occur (PAHO/World Bank, 2004).

Climate change and urban heat island effects are likely to exacerbate the risk of heat waves (Wilby, 2007; Haines *et al.,* 2006; Lisø *et al.,* 2003) and will impact vulnerable social groups (eg elderly, young, sick) particularly but will also have an impact on energy use and economy. Building design is not adequate for an existing rising trend in (particularly night-time) temperatures in Japan and thus will require recognition and attention in the context of longer term climate change adaptation (Shimoda, 2003). Building for safety (Aysan, 1993; Aysan *et al.,* 1995; Coburn *et al.,* 1995)

The urban and the rural are inextricably linked. Inhabitants of rural areas are often dependent on cities for employment and as a migratory destination of last resort. Cities depend on rural areas for food, water, labour and other resources. All of these (and more) can be impacted by climate related variability and extremes. In either case, it is necessary to identify the many exogenous factors that affect a households' livelihood security. Eakin's (2005) examination of rural Mexico presents empirical findings of the interactions (e.g. between neoliberalism and the opening up of agricultural markets, and the agricultural impacts of climatic extremes) which amplify or mitigate risky outcomes (p. 1936). The findings point to economic uncertainty over environmental risk which most influences agricultural households' decision making (p. 1923).

2.5.2. Environmental Dimensions

Maladaptive human/social-environment relations can put people at risk and increase vulnerability; extreme events and processes due to climate change may exacerbate existing risks. There are key links between development, environmental management and disaster reduction (e.g. Van Aalst and Burton, 2002). Furthermore, it is important to consider property rights which govern the use of natural resources and link social and ecological resilience (Adger, 2000) or vulnerability.

There are many examples of the breakdown of society-environment relations that make people vulnerable to extreme events (Bohle *et al.,* 1994) and highlight the vulnerability of/to ecosystem services (Metzger *et al.,* 2006). Destruction of environmental protection afforded by mangrove forest and other wetland habitats has increased both the exposure and vulnerability of coastal populations to storms in many parts of the world (Badola and Hussain, 2005; Day *et al.,* 2007). Similarly, increasing location of housing in fire-prone areas is giving rise to greater human and property damage from San Francisco (Wisner, 1999) to Sydney (Handmer, 1999). Destruction of forest and other habitat on steep slopes exacerbates erosion of productive soils and amplifies landslide risks. The extent to which this exposure leads to or exacerbates vulnerability requires further analysis of local conditions in which some groups or locvations are less able to anticipate, cope or recover from disasters,

The vulnerabilities arising from floodplain encroachment are typical of the intricate and finely balanced relationships between human-environment systems of which we have been aware for some time (Kates, 1971; White, 1974). Increasing human occupancy can put not only the lives and property of human beings at risk but can damage floodplain ecology. The vulnerability of human beings comes about even in the face of actions designed to reduce the hazard. Structural responses and adaptations (e.g. provision of embankments, channel modification and other physical alteration to the floodplain environment) designed ostensibly to reduce flood risk can have the reverse result. This is variously known as the levee effect (Kates, 1971; White, 1974), the escalator effect (Parker, 1995), or the 'safe development paradox' (Burby, 2006) in which floodplain encroachment increases flood damages, which then induce structural flood protection initiatives, which then reduce perceived hazard and encourage further encroachment, which then initiates a recurrence of the sequence.

"In the case of the generation of new, or the exacerbation of existing hazards associated with human intervention in the environment, research must elucidate the rationale for the type of human intervention undertaken, the limits and opportunities the environment presents when faced with such interventions and the options or alternatives that may exist for achieving the same social or economic goals but without the generation of such adverse environmental impacts and results" (Lavell, 1999a, 2000; ICSU-LAC, 2009).

2.5.3. Economic Dimensions

This dimension includes economy as a *hazard* – a trigger for an extreme event; as an *outcome* of an extreme event; and as a *condition* of vulnerability to an extreme event. While all vulnerability dimensions are complex and difficult to measure, the economic dimension has some challenges in both delineating the boundaries of concern and quantifying the evidence. “What is known is only a small part of what matters. Many climate change impacts have been identified but not estimated, and there are undoubtedly yet to be identified impacts too. Some of these impacts are clearly negative, and some clearly positive.” (Tol, 2007).

[INSERT TABLE 2-2 HERE
Table 2-2: People exposed to and killed in disasters in low and high human development countries, respectively, as a percentage of total number of people exposed to and killed by disasters. Source: Birkmann, 2006a: 174 (after Peduzzi, 2005).]

Economic vulnerability can be understood as the susceptibility of the economic system including public and private sectors to potential (direct) disaster damage and loss (Rose, 2000; Mechler, 2004) and refers to the ability of affected individuals, communities, businesses and governments to absorb or cushion the damage (Rose 2004). The degree of economic vulnerability is exhibited post event by the magnitude and duration of the indirect follow on effects. These effects can comprise business interruption costs to firms unable to access inputs from their suppliers or service their customers, income losses of households unable to get to work, or the deterioration of the fiscal stance post disasters as less taxes are collected and significant public relief and reconstruction expenditure is required. On a macroeconomic level, adverse impacts include effects on GDP, consumption and the fiscal position (Otero and Marti, 1995). Key drivers of economic vulnerability are low levels of income and GDP, constrained tax revenue, low domestic savings, shallow financial markets and high indebtedness with little access to external finance (OAS, 1991; Benson and Clay 2000; Mechler, 2004).

Economic vulnerability to external shocks, including natural disasters, has been inexactly defined in the literature and conceptualizations often have overlapped with risk, resilience or exposure. One line of research focussing on financial vulnerability, as a subset of economic vulnerability, framed the problem in terms of risk preference and aversion, a conceptualization more common to economists. Risk aversion denotes the ability of economic agents to financially absorb risk (Arrow and Lind, 1970). An agent is considered averse to risk if it cannot easily absorb losses and, absent further means to reduce risk, requires informal or formal outside mechanisms for sharing risk. There are many ways for absorbing the financial burdens of disasters, with market-based insurance being one, albeit prominent, option. Households often use informal mechanisms relying on family and relatives abroad; governments may simply rely on their tax base or international assistance. Yet, it is a fact that in the face of large and covariate risks, such ad hoc mechanisms often break down, particularly in developing countries (see Linnerooth-Bayer and Mechler, 2007).

Research on financial vulnerability to disasters has hitherto focused on developing countries’ financial vulnerability describing financial vulnerability as a country’s ability to access domestic and foreign savings for financing post disaster relief and reconstruction needs in order to quickly recover and avoid substantial adverse ripple effects (Mechler et al., 2006; Cardona, 2009; Cummins and Mahul, 2008; Marulanda et al, 2008a). Given reported and estimated substantial financial vulnerability and risk aversion in many exposed countries, as well as the emergence of novel public-private partnership instruments for pricing and transferring catastrophe risks globally, has motivated developing country governments, as well as development institutions, NGOs and other donor organizations, to consider pre-disaster financial instruments as an important component of disaster risk management (Linnerooth-Bayer, Mechler and Pflug, 2005).

Human vulnerability to natural hazards and income poverty are largely co-dependent (UNISDR, 2004; Adger, 1999) but poverty does not equal vulnerability (e.g., Blaikie *et al.,* 1994). Given the relationship between poverty and vulnerability, it can be argued (Tol *et al.,* 2004) that economic growth could reduce vulnerability (with caveats). However, increasing economic growth would not necessarily decrease climate impacts. It has the potential – indeed the likelihood – of simultaneously increasing greenhouse gas emissions.). Conversely, would reducing greenhouse gas emissions, with a likely concomitant reduction in economic growth, necessarily reduce the impacts of climate change? There are many questions about the likely impacts of varying economic policy changes (Tol *et al.,* 2004). Some vulnerability factors are closely associated with certain types of development models and initiatives (UNISDR, 2004; UNDP, 2004) but the picture is complex.

2.5.3.1. Work and Livelihoods

Work and livelihoods are impacted by extreme events and by the responses to extreme events. Humanitarian/disaster relief in response to extreme events can induce dependency and weaken local economic systems (references) but livelihood-based relief is of growing importance (references –Mihir Bhatt/All India Disaster Mitigation Institute). This recognition of social vulnerability through a lack of, or shock to, the ways people make a living or subsist, comes out of the development field's work on Sustainable Livelihoods Approaches (Chambers and Conway, 1992; Carney *et al.,* 1999; Ashley and Carney, 1999). This recognizes disasters and extreme events as stresses and shocks within livelihood development processes (Cannon *et al.,* 2003) (see Kelman and Mather, 2008, for a discussion of cases applying it to volcanic events).

Livelihoods can be precarious –even those in developed countries not thought to be obviously vulnerable. The recent global economic downturn will have impacts on a diverse group of people's vulnerability status (individuals' economic position, livelihood/employment, reduction in donors' contributions to mitigation/adaptation and response). Market systems and sectors likely to be affected by, and to different degrees vulnerable to, climate change include livestock, forestry and fisheries industries and energy, construction, insurance, tourism and recreation sectors (Schneider *et al.,* 2007: 790).

The Stern Review underlines the significance of economic dimensions of climate change and estimates that doing nothing about climate change could lead to damage costs of 20% of global GDP (Stern, 2006 p. Vi).

2.5.3.2. Wealth

Much of the literature on exposure and vulnerability deals with a lack of wealth – i.e. poverty – rather than the wealthy themselves. However, wealthy countries and wealthy individuals are increasingly exposed to climate related extremes through lifestyle choices which place them in hazard-prone locations. The extent to which they are also vulnerable is a moot point. As Cutter et al (200) point out, "wealth enables individuals to absorb and recover from losses more quickly using insurance, social safety nets, and entitlement programs" (page 717) and thus they are made less vulnerable. However, at larger scales, aggregations of such individuals could make communities and the infrastructure on which they depend, vulnerable to economic impact. The insurance safety net can be removed or made extremely costly if insurance and reinsurance companies face excessive or repeated payouts.

Furthermore, it is not just the risk of economic damage in rich countries themselves but the way such disasters can disrupt global economies (Mitchell 1999: 32). The 1987 windstorm in the UK closed down the London Stock Exchange and may have helped prompt the worst international stock market crisis since the Great Depression (Mitchell et al 1989).

2.5.4. Social Dimensions

The social dimension is itself multi-faceted, and encompasses several of the issues discussed above. Primarily, it focuses on societies and collectivities, rather than individuals, however, some still use the 'individual' descriptor to clarify issues of scale and units of analysis (Adger and Kelly, 1999; O'Brien *et al.,* 2008). Notions of the individual are also useful when considering for instance psychological trauma in disasters (e.g. Few, 2007) although analysis is usually aggregated to a defined social group (men, women, etc.); and risk perception (Slovic, 2000; Oppenheimer and Todorov, 2006; Schneider *et al.,* 2007). The social dimension includes elements such as: education, health and well-being, but also housing (link to built environment); as well as work/livelihoods (discussed above under 'Economic Dimensions') and elements related to the cultural aspects of collectivities of people at various levels (discussed below under "Cultural Dimensions") as well as Institutional and Governance Dimensions, such as forms of social networking and social capital/assets, political vulnerability; as well as interaction related to migration and land tenure.

2.5.4.1. Education

The education dimension ranges across the vulnerability of educational building structures; issues related to access to education; and also access to information and knowledge. Priority 3 of the Hyogo Framework for Action 2005-2015 recommends the use of knowledge, innovation and education to build a culture of safety and resilience at all levels (UNISDR, 2007a). A well-informed and motivated population can lead to disaster risk reduction but it requires the collection and dissemination of knowledge and information on hazards, vulnerabilities and capacities. However, "It is not information per se that determines action, but how people interpret it in the context of their experience, beliefs and expectations. Perceptions of risks and hazards are culturally and socially constructed, and social groups construct different meanings for potentially hazardous situations" (McIvor and Paton, 2007: 80).

Many lives have been lost through the inability of education infrastructure to withstand extreme events. This has been particularly evident in the case of earthquake hazards but it is also seen in storms and floods for example. Even without fatalities, there is still considerable physical and psychological damage caused to children, their teachers and the wider community through school building damage. Improving education infrastructure safety can have less obvious benefits, as can be seen in the case of cyclone-prone Madagascar where significant cyclone damage occurs each year. The Malagasy Government initiated the Development Intervention Fund IV (FID1 IV) project to reduce cyclone risk, including in school construction and retrofitting. In doing so, awareness and understanding of disaster issues was increased within the community (UNISDR 2007c).

The impact of extreme events can limit the ability of parents to afford to educate their children or require them (especially girl children) to work to meet basic needs. Improved educational (and health) status can help reduce vulnerability and can limit human losses in a disaster *(*UNISDR, 2004).

2.5.4.2. Health and Well-Being

The health dimension includes differential effects in different regions and on different social groups (Few, 2007; McMichael *et al.,* 2003; Haines *et al.,* 2007; van Lieshout *et al.,* 2004; Costello *et al.,* 2009). It also includes, in a link to the institutional dimension, environmental health and public health issues, infrastructure and conditions (Street *et al.,* 2005).

The health dimensions of disasters are difficult to measure because of difficulties in attributing the health condition directly to the extreme event because of secondary effects; in addition, some of the effects are delayed in time, which again makes it difficult to attribute to the event (Bennet, 1970; Hales *et al.,* 2003).

Situational/context specific analysis is needed because there is considerable variation in vulnerability of different social groups to health impacts. For example, in the case of temperature related events, seasonal variations in winter mortality in temperate countries suggest the elderly (75 and older) are particularly vulnerable (Hales *et al.,* 2003). Evidence from heat waves show vulnerability is through a complex mix of factors including age, physiological status, gender norms influencing behaviour (e.g. excess deaths occurring through exertion in high temperatures) (Hales *et al.,* 2003). Klinenberg's (2002) study of the Chicago heatwave of 1995 identified that older males were twice as likely to die as older females who might have been considered to be the more vulnerable group. Where other studies have broken down fatalities and morbidity by social group, greater vulnerability has varied (Hales *et al.,* 2003). Thus, we do not have a simple bivariate relationship between extreme events and health but they are moderated and mediated by a sometimes complex set of other variables.

2.5.5. Cultural Dimensions

The broad term 'culture' embraces a bewildering complexity of elements that can relate to a way of life, behaviour, taste, ethnicity, ethics, values, beliefs, customs, ideas, institutions, art and intellectual achievements that affect, are produced or are shared by a particular society. In essence, all these characteristics can be summarised to describe culture as 'the expression of humankind within society'. (Aysan and Oliver, 1987)

Culture is variously used to describe many aspects of extreme risks from natural disasters or climate change, including the:

- Cultural aspects of risk perception
- Negative culture of danger/ vulnerability/ fear
- Culture of humanitarian concern
- Culture of organizations/ institutions and their responses
- Culture of preventive actions to reduce risks, including the creation of buildings to resist extreme climatic forces
- Ways to create and maintain a ‘Risk Management Culture’ or a ‘Safety Culture’.

In relation to our understanding of risk certain cultural issues need to be noted. Typical examples are cited below:

- *Ethnicity and Culture*. Deeply rooted cultural values are a dominant factor in whether or not communities adapt to climate change. For example recent research in Northern Burkina Faso, indicates that the level of adaptation to climate change is related to ethnicity and the issue of values and culture in adaptation and vulnerability to climate change. Two ethnic groups, were compared and it was shown that despite their presence in the same physical environment and their shared experience of climate change, the two groups have adapted very different strategies due to cultural values and historical relations. Neilson, et al (2008)
- *Locally Based Risk Management Culture*. Wisner (2003) has argued that the point in developing a ‘culture of prevention’ is to build networks at the neighbourhood level capable of ongoing hazard assessment and mitigation at the micro level. He has noted that while community based NGO’s emerged to support recovery after the Mexico City and Northridge earthquakes, these were not sustained over time to promote risk reduction activities. This evidence confirms other widespread experience indicating that ways still need to found to extend the agenda of Community Based Organisations (CBO’s) into effective action to reduce climate risks and promote adaptation to climate change.
- *Conflicting Cultures: who benefits, and who loses when risks are reduced?* A critical cultural conflict can arise when private actions to reduce disaster risks and by adapting to climate change by one party have negative consequences on another. This regularly applies in river flood hazard management where upstream measures to reduce risks can significantly increase downstream threats to persons and property. Neil Adger and his colleagues note that ‘actions are likely to be undertaken by individuals or businesses if they perceive early rewards or benefits from their actions, such as reduced damages from extreme weather events or cheaper insurance.’ Therefore, if risk reduction actions are to occur the key players must bear all the costs and receive all the benefits from their actions. Adger, (2009)

These examples are reminders that all actions to reduce risks, or adapt to them occur within a cultural context. Therefore, a key element in risk assessment is to review the likely cultural constraints on a proposed set of actions as well as their anticipated consequences on society, its citizens, and their deeply held values.

Traditional behaviours tied to local (and wider) tradition and cultural practices can increase vulnerability. For example, unequal gender norms (see above), traditional uses of the environment which have not adapted to changed environmental circumstances. However, local or indigenous knowledge can reduce vulnerabilities too (Gaillard).

Cultural dimensions to the perception of risk/hazard also create vulnerabilities. The early hazards paradigm literature (White, 1974; Burton, Kates and White, 1978) referred often to fatalistic attitudes, which resulted in inaction in the face of disaster risk but Schmuck-Widmann (2000), in her social anthropological studies of char dwellers in Bangladesh, noted how a belief that disaster occurrence and outcomes were in the hands of God did not preclude preparatory activities. Perception of risk depends on the cultural and social context (Slovic, 2000; Oppenheimer and Todorov, 2006; Schneider *et al.,* 2007).

Motivational and attitudinal factors which Anderson and Woodrow (1989) identify as important in determining vulnerabilities and capacities, are culturally specific.

Research on culture includes topics such as perceptions and risk (eg. Gaillard, 2007; de Silva, 2006), the role of faith in the recovery process following a disaster (eg. Massey and Sutton, 2007; Davis and Wall 1992), religious explanations of nature (eg. Orr, 2003; Peterson, 2001), and the role of religion in influencing positions on environment and climate change policy (eg. Kintisch, 2006; Hulme, 2009), as well as religion and vulnerability (Schipper, 2010; Chester, 2005; Elliott, 2006; Guth *et al.,* 1995). A key research area under this heading is cultural theory (closely associated with the work of Mary Douglas (1966)) which attempts to explain how people interpret their world and define risk according to their worldviews: hierarchical, fatalistic, individualistic, and egalitarian (Douglas and Wildavsky, 1982). While cultural theory has been criticized (lack of empirical testing,

Marris et al (1998) reinforce the importance of understanding differential risk perceptions in a cultural context. Too often policies and studies focus on 'the public' in the aggregate (p. 646) and too little on the needs and interests of different social groups. One aspect of vulnerability reduction is through individual risk perception and this demands recognition of diversity.

2.5.6. Institutional and Governance Dimensions

The institutional context of vulnerability to extreme events is a key determinant of vulnerability (Adger, 1999). Expanding the institutional domain to include political economy (Adger, 199) and different modes of production - feudal, capitalist, socialist (Wisner, 1978) –raises questions about the vulnerability *of* institutions and vulnerability caused *by* institutions (including government).

The institutional dimension includes the relationship between policy setting and policy implementation in risk and disaster management; top-down approaches assume policies are directly translated into action on the ground; bottom-up approaches recognise the importance of other actors in shaping policy implementation (Urwin and Jordan, 2008). Twigg's categorization of the characteristics of the ideal disaster resilient community (Twigg, 2007) identifies the important relations between the community and the enabling environment of governance at various scales in creating resilience, and by inference, reducing vulnerability. This set of characteristics also refers to institutional forms for, and processes of engagement with, risk assessment, risk management, and hazard and vulnerability mapping which have been championed by institutions working across scales to create the Hyogo Framework for Action (UNISDR, 2007a) and associated tools (UNISDR, 2007b; ProVention Consortium, 2009) with the goal to reduce disaster risk and vulnerability.

A lack of institutional interaction and integration between disaster risk reduction, climate change and development may mean policy responses are redundant or conflicting (Schipper and Pelling, 2006). And so the institutional model operational in a given place (and time) – more or less participatory, deliberative and democratic; integrated or disjointed - could be an important factor in vulnerability creation or reduction (Comfort *et al.,* 1999). However, further study of the role of institutions in influencing vulnerability is called for (O'Brien *et al.,* 2004).

Institutions have been defined in a broad sense to include "habitualized behaviour and rules and norms that govern society" (Adger, 2000) and not just the more typically understood formal institutions. This allows a discussion of institutional structures such as property rights and land tenure issues (Toni and Holanda 2008), which govern natural resource use and management. It forms a bridge between the social and the environmental/ecological dimensions and can create induce sustainable or unsustainable exploitation (Adger 2000). This broader understanding of the institutional dimension also takes us into a recognition of the role of social networks, community bonds and organizing structures and processes which can buffer the impacts of extreme events (Nakagawa and Shaw 2004) partly through increasing social cohesion but also recognizing ambiguous or negative forms (UNISDR 2004: 24). For example, social capital/assets (Putnam; Portes 1998) – "the norms and networks that enable people to act collectively" (Woolcock and Narayan 2000, 226) – have a role in vulnerability reduction (Pelling 1998). Social capital (or its lack) is both cause and effect of vulnerability (the conflation is regarded critically by Adger 2003: 390) and thus can be either positive benefit or negative impact; to be a part of a social group and accrue social assets is often to indicate others' exclusion.

_____ START BOX 2-1 HERE _____

Box 2-1. Cross-Cutting Dimensions and Intersectionality

Almost all of the dimensions discussed above generate differential effects. Indeed, research evidence of the differential vulnerability of social groups is extensive and raises concerns about the disproportionate effects of climate change on identifiable, marginalized populations (Kasperson and Kasperson 2001; Bohle *et al.,* 1994; Thomalla *et al.,* 2006). Particular groups and conditions have been identified for example race/ethnicity, socioeconomic class, gender, age (both the elderly and children), migration, and housing tenure (whether renter or owner) as among the most common social vulnerability characteristics (Cutter and Finch, 2008). Betty Hearn Morrow (1999) extends and refines this list to include: residents of group living facilities; ethnic minorities (by language); recent residents/immigrants/migrants; physically or mentally disabled; large households; renters; large concentrations of children/youth; poor households; the homeless (see also Wisner, 1998); women-headed households; tourists and transients. But as Adger and Kelly (1999) point out, the state of vulnerability is defined by a specific population at a particular scale and aggregations (and generalizations) are less meaningful and so such descriptors must be used with caution.

There is a literature on all these groups but one of the largest has been on gender and on women in particular (e.g., Enarson and Morrow, 1998). However, this body of literature is relatively recent, particularly in a developed world context, given the longer recognition of gender concerns in the development field (Fordham 1998). Additionally, the gender literature has led on the important acknowledgement of resilience/capacity/capability and not always a fixed vulnerability in these identified groups. The vulnerability label can reinforce notions of passivity and helplessness.

_____ END BOX 2-1 HERE _____

[INSERT TABLE 2-3 HERE:
Table 2-3: Differential exposure and vulnerability of identified groups.]

2.5.7. Interactions and Integrations

This section began by breaking down the vulnerability concept into its constitutive parts with evidence derived from a number of discrete research and policy communities (e.g. disaster risk reduction; climate change adaptation; environmental management; and poverty reduction) that have largely worked independently (Thomalla *et al.,* 2006: 39). Increasingly it is recognized that collaboration and integration is necessary both to set appropriate policy agendas and to better understand the topic of interest. Although McLaughlin and Dietz (2008) make a critical analysis of the absence of an integrated perspective on the interrelated dynamics of social structure, human agency and the environment

Food security/vulnerability is a useful example of where reviewing singular dimensions of vulnerability will not provide an appropriate level of analysis (e.g. the early recognition that so-called natural disasters were not natural at all (O'Keefe *et al.,* 1976) and where crossing disciplinary boundaries (e.g. those separating disaster and development, or developed and developing countries) has been fruitful (see Hewitt, 1983). In analyzing the vulnerability of food systems (to put it broadly), we must note the combined contributions of inter alia: physical location in susceptible areas; political economy (Watts and Bohle, 1993); entitlements in access to resources (Sen, 1981); social capital and networks (Eriksen, Brown and Kelly, 2005); landscape ecology (Fraser, 2006); human ecology; political ecology (Pulwarty and Riebsame, 1997; Holling, 2001).

Coupled human/social–environment systems (Turner *et al.,* 2003; Holling, 2001)

While this section has identified a number of discrete dimensions of vulnerability that often arise out of focused research on singular elements, their application benefits from recognition of the dynamic nature of their interactions and in their necessary integration.

2.5.7.1. Migration and Displacement

Migration is both a condition of, and a response to, vulnerability – especially political vulnerability created through conflict, which can drive people from their homelands. Increasingly it relates to economic and environmental refugees and migrants but can also refer to those who do not cross international borders but become internally displaced persons as a result of extreme events in both developed and developing countries (e.g., Myers *et al.,* 2008).

Although data on climate change forced displacement is incomplete, it is fairly clear that the many outcomes of climate change processes will be seen and felt as disasters by the affected populations (Oliver-Smith 2009). For people affected by disasters, subsequent displacement and resettlement often constitute a second disaster in their lives. Cernea's well-known Impoverishment Risks and Reconstruction approach to understanding (and mitigating) the major adverse effects of displacement outlines the eight basic risks to which people are subjected by displacement as: landlessness, joblessness, homelessness, marginalization, food insecurity, increased morbidity, loss of access to common property resources, and social disarticulation (Cernea 1996). When people are forced from their known environments, they become separated from the material and cultural resource base upon which they have depended for life as individuals and as communities (Altman and Low 1992). The material losses most often associated with displacement and resettlement are losses of access to customary housing and resources. Displaced people are often distanced from their sources of livelihood, whether land, common property (water, forests, etc) or urban markets and clientele (Koenig 2009). Disasters and displacement may sever the identification with an environment that may once have been one of the principle features of cultural identity (Oliver-Smith 2006: 47-50). Displacement for any group can be a crushing blow, but for indigenous peoples it can prove mortal. The environment and ties to land are considered to be essential elements in the survival of indigenous societies and distinctive cultural identities (Colchester 2000). The displacement and resettlement process has been consistently shown to disrupt and destroy those networks of social relationships on which the poor depend for resource access, particularly in times of stress (Scudder 2005; Cernea 1996). Reconstruction and resettlement projects frequently stress efficiency and cost containment over restoration of community. Such top-down initiatives have a poor record of success because of a lack of regard for local community resources (de Wet 2006). Planners often perceive the culture of uprooted people as an obstacle to success, rather than as a resource.

2.5.8. Timing and Timescales

Two cross-cutting themes of particular importance for understanding the dynamic changes within exposure, vulnerability and risk are different time scales and different spatial and functional scales.

Timing and time scales are important cross-cutting themes that need more attention when dealing with the identification and management of extreme climate and weather events, disasters and adaptation strategies. The first key issue when dealing with timing and time scales is the fact that different hazards and their reoccurrence intervals might fundamentally change in terms of the time dimension. This implies that the identification and assessment of risk, exposure and vulnerability needs also to deal with different time scales and in some cases might need to consider various time scales. At present most of the climate change scenarios focus on climatic change within the next 100 or 200 years, while often the projections of vulnerability just use the present socio-economic data. However, a key challenge for enhancing our knowledge of exposure and vulnerability as key determinants of risk requires as well improved data and methods to project and identify directions in demographic, socio-economic and political trends that can adequately illustrate potential increases or decreases in vulnerability with the same time horizon as the biophysical projections (see Birkmann *et al.,* 2010).

Furthermore, it is important to consider the time dependency of risk analysis, particularly if the analysis is conducted at a specific point in time. Newer research underlines, that particularly exposure – especially the exposure of different social groups - is a very dynamic element that changes not only seasonal, but also during the day. A recent study of Setiadi et al. 2010 for the coastal city of Padang underlines, that a higher proportion of more vulnerable population groups is exposed in the high risk zone close to the sea due to the different mobility and activity patterns of female and male population during the day. The authors conclude that the major differences in the main activity profile of female and male population in the city of Padang has serious consequences in terms of the higher spatio-temporal exposure of female population to coastal hazards.

The analysis of the activity patterns showed that the majority of the female population are most likely to conduct their daily activities at home or in the neighbourhood. This situation is also strengthened by the fact that the female population work mainly in the service and trading sectors, of which about 30% are conducted at home. Thus the socio-demographic exposure within the city of Padang to coastal hazards various significantly between the morning-, afternoon- and night time (see Figure 2-3). The impacts of the 2004 Indian Ocean Tsunami also exemplify the differing spatial and temporal vulnerabilities of different social groups. Women located on the seashore preparing for the fish catch and in their homes rescuing children, died in greater numbers than men working out to sea in their boats (Doocy et al 2007). Consequently, time scales and dynamic changes over time have to be considered carefully when aiming at conducting risk and vulnerability assessments to extreme events and creeping changes in the context of climate change. Additionally, also changes in the hazard frequency and timing of hazard occurrence for example during the year will have a strong impact on the ability of societies and ecosystems to cope and adapt to these changes. These time scale related challenges and problems have been identified e.g. for ecosystems in the North of Peru under the influence of El Nino.

[INSERT FIGURE 2-3 HERE:
Figure 2-3: Difference between female-male population during morning, afternoon and night, for the coastal city of Padang, demonstrating differential exposure of women over time of day in the high risk zone close to the sea (Setiadi et al., 2010).]

Lastly, different time scales are also an important constrain when dealing with the link between disaster risk reduction and climate change adaptation. In many areas disaster risk reduction operates on different times scales compared to the strategies and measures of climate change adaptation and mitigation (see Birkmann/Teichman 2010 and Thomalla *et al.,* 2006: 41).

The timing of events may also create 'windows of vulnerability,' periods in which the hazards are greater because of the conjunction of circumstances" (Dow, 1992). Time is a cross cutting dimension that always needs to be considered but particularly so in the case of anthropogenic climate change, which may be projected some years into the future (Füssel, 2005). In fact, this time dimension is regarded (Thomalla *et al.,* 2006) as a key difference between the disaster management and climate change communities. To generalize somewhat, the former typically (with obvious exceptions such as slow onset disasters such as famine or desertification) must deal with fast onset events, in discrete, even if extensive, locations, requiring immediate action. The latter, however, occur in a dispersed form over lengthy time periods and are much more challenging in their identification and measurement (Thomalla *et al.,* 2006: 41). Risk perception may be reduced (Leiserowitz, 2006: 52) for events remote in time and/or space, such as some climate change impacts are perceived to be. Different time scales are also an important constraint when dealing with the link between disaster risk reduction and climate change adaptation. In many areas, disaster risk reduction operates on different times scales compared to the strategies and measures of climate change adaptation and mitigation (see Birkmann/Teichman 2010 and Thomalla *et al.,* 2006: 41). However, the affirmation that disaster risk management is short term and adaptation long term is a misconception and should be clarified. It appears to stem from disaster management considered narrowly as immediate response and coping but if we consider risk reduction more broadly then when we build a nuclear facility to resist 10000 year earthquakes flood barriers to resist 1000 year storm surges, we are not short-terming. All modern prospective risk management debates involve security considerations decades ahead for production, infrastructure, houses, hospitals etc.

"If the vulnerability of a system or its exposure to the hazard is expected to change significantly during the time period considered in an assessment, statements about vulnerability should specify a temporal reference, *i.e*., the point in time or period of time that they refer to. This is particularly relevant for vulnerability assessments addressing anthropogenic climate change, which may have a time horizon of several decades or longer." (Fussell, 2005). Leiserowitz' survey analysis (2006) concludes that, although many Americans believe climate change to be a real and serious problem, it lacks urgency because it is risk they believe "is more likely to impact people and places far distant in space and time".

2.5.9. Spatial and Functional Scales

Spatial and functional scales are another cross cutting theme that is of particular relevance when dealing with the identification of exposure and vulnerability to extreme events and climate change. Leichenko and O'Brien (2002) conclude that in many areas of climate change and natural hazards societies are confronted with dynamic vulnerability, meaning that processes and factors that cause vulnerability operate simultaneously at multiple scales making traditional indicators insufficient (Leichenko and O'Brien 2002). Also Turner et al. (2003) stress that vulnerability and resilience assessments need to consider the influences on vulnerability from different scales, however, the practical application and analysis of these interacting influences on vulnerability from different spatial scales is a major challenge and in most cases not sufficiently understood. Furthermore, vulnerability analysis particularly linked to the identification of institutional vulnerability has also to take into account the various functions scales that climate change, natural hazards and vulnerability as well as administrative systems operate on. In most cases current disaster management instruments and measures of urban or spatial planning as well as water management tools (specific plans, zoning, norms) operate on different functional scales compared to climate change. Even the various hazards that climate change is likely to modify or to intensify encompass different functional scales that can not be sufficiently captured with one approach (see Birkmann/Teichman 2010). Consequently, functional and spatial scale mismatches might even be part of institutional vulnerabilities that limit the ability of governance system to adequately respond to hazards and changes induced by climate change.
[more literature references will be included]

_____ START BOX 2-2 HERE _____

Box 2-2. Cross-Cutting Dimensions and Intersectionality: the Garifuna Women of Honduras.

The Garifuna women of Honduras could be said to show multiple vulnerability characteristics: they are women – the gender often made vulnerable by patriarchal structures worldwide; they come from Honduras, a developing country at risk of many hazards; they belong to a marginalised ethnic group descended from African slaves; and they depend largely on a subsistence economy and a lack of education, health and other resources. However, despite these markers of vulnerability, there are examples of Garifuna women organizing to reduce their communities' risks of disasters and to protect and develop their livelihood opportunities (Fordham, Gupta, Shende, forthcoming).

_____ END BOX 2-1 HERE _____

2.6. Vulnerability Profiles

2.6.1. Introduction

Vulnerability profiles are a key input to risk assessments. A description of the vulnerable situation (who, what and where) is an important first step to avoid misunderstandings around vulnerability. Profiling is simply defined as a formal summary or analysis of data, often in the form of a graph, map or table, representing distinctive features or characteristics of the particular system being referred to.

Vulnerability depends critically on context, and the factors that make a system vulnerable to hazards will depend on the nature of the system and the type of hazard in question (Brooks, 2005). The term 'vulnerability' may refer to the vulnerable system itself, e.g., low-lying islands or coastal cities; the impact to this system, e.g., flooding of coastal cities and agricultural lands or forced migration; or the mechanism causing these impacts, e.g., disintegration of the West Antarctic ice sheet (IPCC, 2007). Many impacts, vulnerabilities and risks merit particular attention by policy-makers due to characteristics that might make them *key*. Key impacts that may be associated with key vulnerabilities are found in many social, economic, biological and geophysical systems, and are associated with many climate sensitive systems, including, for example, food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets, and modes of oceanic and atmospheric circulation, among others.

2.6.2. Agriculture and Food Security

Vulnerability in the agriculture sector can be indicated by combining elements of exposure, sensitivity, and adaptive capacity to climate change, variability and extremes. Exposure can be expressed in terms of the biophysical impacts of the hazards, which in this context would be the changing patterns of extreme events. These changes will affect agriculture and livestock production depending on several factors such as crop type, CO_2 fertilization, and other multiple stressors. Sensitivity to climate change and extreme weather events can be manifested in the presence of other external factors such as water stress, land degradation rates, and the dependency of the economies on agriculture. Other areas which are low-lying are more sensitive to the impacts of rising sea levels and storm surges. Socio-economic variables can also be used to assess the sensitivity of the agriculture sector to climate change, variability and extremes, such as rural population density, % of irrigated land, and agricultural employment (FAO 2004). Several indicators can be used to measure adaptive capacity, such as poverty rates, access to credit, literacy rates, farm income, and agricultural GDP.

Vulnerability also refers to the presence of factors that place people at risk of becoming food insecure. These factors can be external or internal (FAO, 2000). External factors have the nature of: (i) Trends, e.g. depletion of natural resources from which the population makes its living, food price inflation;(ii) Shocks, e.g. natural disasters, conflict; changing extremes due to climate change; (iii) Seasonality, e.g. seasonal employment opportunities, seasonal incidence of disease; and, (iv) Internal factors are the characteristics of people, the general conditions in which they live and the dynamics of the household that restrict their ability to avoid becoming food insecure in the future. The second and third factors are directly related to the changing risks due to extreme events, climate variability and change.

A typical two-step vulnerability assessment would include:

1) Analysis of factors and constraints that negatively affect the agriculture production and threaten food security situation
2) Evaluation of opportunities, which are the positive factors that exist internally in the system or in the external environment, that could potentially contribute to an improvement of the sector's performance or resilience.

In order to build resilience in the agriculture sector and on the people who depend on this sector, the actions must clearly work on the vulnerability components, for example as described schematically below (ADB, 2009) for agriculture sector.

[INSERT FIGURE 2-4 HERE:
Figure 2-4: Relation between vulnerability and building resilience in the agriculture sector (ADB, 2009).]

2.6.3. Human Health

In the context of health risks from extreme weather events, the National Research Council (2001) defines vulnerability as the "extent to which a population is liable to be harmed by a hazard event, and depends on the populations' exposure to the hazard and its capacity to adapt or otherwise mitigate adverse impacts". Nearly all the adverse environmental and social effects of climate change will ultimately threaten human health (physical, nutritional, microbiological, or mental). The dependence of human biology and of collective human ecology on the stability, productivity, and resilience of the natural environment is absolute. Food yields, water flows, air quality, fibre and timber supplies, natural medicinal substances, and climatic stability all underpin population health—and all are threatened by climate change.

Climate change will affect human health through complex systems involving changes in temperature, exposure to extreme events, access to nutrition, air quality and other vectors. Currently small health effects can be expected with very high confidence to progressively increase in all countries and regions, with the most adverse effects in low-income countries. Climate will interact with human health in diverse ways. Those least equipped to respond to changing health threats—predominantly poor people in poor countries—will bear the brunt of health setbacks. Ill-health is one of the most powerful forces holding back the human development potential of poor households. Changing risks from extreme events associated with climate change will intensify the problem (HDR, 2007).

Climate change, variability and extremes may affect health through a range of pathways—e.g., as a result of increased frequency and intensity of heat waves, reduction in cold-related deaths, increased floods and droughts, changes in the distribution of vector-borne diseases, and effects on the risk of disasters and malnutrition. The overall balance of effects on health is likely to be negative and populations in low-income countries are likely to be particularly vulnerable to the adverse effects. The experience of the 2003 heat wave in Europe shows that high-income countries might also be adversely affected. Adaptation to climate change requires public-health strategies and improved surveillance. Mitigation of climate change by reducing the use of fossil fuels and increasing the use of a number of renewable energy technologies should improve health in the near term by reducing exposure to air pollution (Haines, 2006).

The capacity to respond to the negative health effects of climate change relies on the generation of reliable, relevant, and up-to-date information. Strengthening informational, technological, and scientific capacity within developing countries is crucial for the success of a new public health movement. This capacity building will help to keep vulnerability to a minimum and build resilience in local, regional, and national infrastructures. Local and community voices are crucial in informing this process. Weak capacity for research to inform adaptation in poor countries is likely to deepen the social inequality in relation to health.

Policy responses to the public health implications of climate change will have to be formulated in conditions of uncertainty, which will exist about the scale and timing of the effects, as well as their nature, location, and intensity.

A key challenge is to improve surveillance and primary health information systems in the poorest countries, and to share the knowledge and adaptation strategies of local communities on a wide scale. Essential data need to include region-specific projections of changes in health-related exposures, projections of health outcomes under different future emissions and adaptation scenarios, crop yields, food prices, measures of household food security, local hydrological and climate data, estimates of the vulnerability of human settlements (e.g., in urban slums or communities close to coastal areas), risk factors, and response options for extreme climatic events, vulnerability to migration as a result of sea-level changes or storms, and key health, nutrition, and demographic indicators by country and locality.

2.6.4. Freshwater Resources

TBD

[INSERT TABLE 2-4 HERE:
Table 2-4: Vulnerability indicators used in Collins and Bolin (2007).]

2.6.5. Ecosystems

There is a high confidence probability that the resilience of many ecosystems will be undermined by climate change, with rising CO_2 levels reducing biodiversity, damaging ecosystems and compromising the services that they provide (IPCC, 2007).

2.6.6. Coastal Systems and Low-Lying Areas

Coastal vulnerability is a broad term that denotes the risk to various systems, such as human populations, natural ecosystems, managed land use, human habitations and infrastructure, which are exposed to a variety of external events, such as cyclones, storm surges and tsunamis. While most of them are natural events, their incidence is being affected by human induced changes. Climate change is one such process associated with human induced changes in global atmospheric environment which can result in widely varying impacts, such as sea level rise.

Indicators for coastal vulnerability can be grouped in vulnerability classes (Kaiser, 2006):

- Social vulnerability: demography, health, education and work, governance, culture or personal wealth, social networks
- Economic vulnerability: capital value at loss, land loss, labor force, economic information (e.g. GDP, buildings, unemployment rate, dependence on resources, tourism)
- Ecological vulnerability: ecological values and environmental pressure (e.g. protected area, unique ecosystems, managed land, tourism pressure).

Categories for resilience indicators can be grouped in ecological resilience and socio-economic resilience (preparedness, early warning capacity, coping capacity, adaptive capacity, recovery). An indicator system is indicated to provide decision-makers on local and national level with an effective tool, helping them to analyze and understand the risk a coastal area is exposed to. The choice of appropriate coastal vulnerability indicators depends on the type of coastal hazard, and especially social risk and vulnerability indicators may differ according to the development status or socio-cultural and economic state of a region.

In the real world, vulnerability assessment could be a part of a larger assessment activity on the ground such as environmental profiling, looking at factors affecting a system and the possible ways to reduce negative impacts and harness opportunities. For example in Box 2-3, a coastal environmental profiling that identified key values and management strategies in Bali. In the context of changing risks, the driving forces include the extreme climatic events and biophysical processes affecting the coastal environment. Aside from establishing qualitative and quantitative baseline information, an environmental profile identifies data gaps that require further research or monitoring. The environmental profiling activity also enhances the awareness of stakeholders. The environmental profile is essentially the basis for developing coastal strategy and conducting initial risk assessment. The data collected through environmental profiling are also useful inputs for the establishment of an integrated information management system.

_____ START BOX 2-3 HERE _____

Box 2-3. Coastal Environmental Profiling in Bali.

The environmental profiling and stakeholder consultation identified the key values, threats, and management strategies for the site. Aside from its historical and cultural values, Bali is critically important for coastal tourism, agriculture, capture fisheries and aquaculture, shipping, and human settlements. They described how the coastal habitats – particularly mangrove, seagrass beds and coral reefs – reduce the island's vulnerability to natural hazards and maintain essential ecological processes and biological diversity. The identified key threats to these values included beach erosion, destruction of coastal habitats, indiscriminate land conversion for commercial purposes, industrial and municipal wastes, multiple use conflicts, lack of interagency coordination, and weak environmental management capacity. There was a consensus that Integrated Coastal Management (ICM) is the best organizing framework to address such complex problems and issues. Some specific management recommendations relate to conservation of coastal habitats, integrated land and sea uses, establishing a waste management program, increasing the awareness level of the various stakeholders, and building the management capacity at the local level.

_____ END BOX 2-3 HERE _____

2.6.7. Industry and Settlements

Urban areas, cities and mega-cities as well as peri-urban areas are also highly vulnerable and at risk due to climate change and extreme events, although major attention has been given until now to rural areas and climate change. Vulnerability and risk in urban areas results from socio-economic transformations as well as from an increasing exposure of urban areas to the impacts of climate change (sources). One of the most vulnerable urban settings are informal settlements where marginalized population groups are living. These areas are increasing; they are in general characterized by a lack of access to basic services and a lack of political power as well as a high hazard exposure due to the necessity to settle in marginal areas.

Additionally, it is important to note that various cities depend on their hinterland and on functioning critical infrastructures in order to function and to provide basic functions such as housing, work and recreational services. Recent extreme weather events have showed that in both the South and North cities are particularly vulnerable due to the dependency on critical infrastructures, such as water supply, electricity, sewage sytems , transport and communication systems. A temporal or irreversible break down of critical infrastructures due to extreme events is therefore a key profile of the vulnerability and risks within urban areas. In general “critical infrastructures” are defined as organizations, institutions and services which are essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people. Their breakdown or malfunction can lead to severe supply shortfalls, substantial disruptions of the public safety and other serious consequences (see BMI 2005, European Commission 2008). The interdependency of various critical infrastructures (see Rinaldi et al. 2001), particularly the dependency on electricity for many services, is a serious threat for cities and in some cases increases their vulnerability to climate change related hazards. Risks in urban areas that are linked on the one hand to the dependency of urban societies on critical infrastructures and their functioning and on the other hand to the susceptibility and limited redundancy and replaceability of these critical infrastructures are a characteristic of new systemic risks that are closely embedded in specific development patterns of modern societies (IRGC 2009, Beck 2006).

2.7 Trends in Exposure and Vulnerability

2.7.1. Identifying Trends in Vulnerability and Exposure

As defined in Section 2.2 vulnerability is related to the degree to which human beings and their activity systems are damaged by natural or socio-natural events. Vulnerability then is very much associated with the level of exposure of society and the degree of sensitivity of a particular societal element at multiple scales (from the individual to the national).

In relation to climate, exposure has two broad meanings in the literature. How persons, property, infrastructure, goods and the environment itself come into contact with potentially damaging events matches the ideas surrounding exposure in the hazards, disasters and climate change literature. Exposure in this sense is very much dependent on location (direct or indirect proximity) and physical susceptibility or resistance to damage. From a poverty and development persepctive exposure relates to an aggregate measure of human welfare that integrates environmental or physical characteristics of where a person lives with social, economic and political factors that may work against protection from harm due to extreme climate events. Given these understandings, trends in exposure will be related to changes in the physical location and place and physical susceptibility along with alterations to a range of human welfare factors. Although exposure is complex, a consideration of trends in exposure factors whether they be physical or otherwise is necessary for a holistic understanding of vulnerability itself and trends in vulnerability.

As neither the environment (Ahmed et al., 2009; Ford et al., 2009) nor society are static (Jasparro and Taylor, 2008), then exposure and vulnerability are dynamic variables and accordingly will change both over time and space due to climatic variability and socio-economic and political-cultural changes. The dynamic nature of exposure and vulnerability will require that policy is flexible and able to cope with changing circumstances and “surprises” both in terms of changing environmental and societal conditions. This section therefore considers trends in environmental, economic, social and cultural factors that may alter the exposure and vulnerability profiles at a variety of scales.

2.7.2. Physical Dimensions

2.7.2.1. Geography, Location, and Place

TBD (from chapter 4)

2.7.2.2. Settlement Patterns and Development Trajectories

By 2030 it is estimated that at least 60 percent of the globe's population will be urbanised. In addition to the fact that the sheer numbers of urban dwellers will represent a large pool of potentially vulnerable individuals, concentrated into relatively small areas, the unintentional modification of environmental processes by urban areas may enhance the vulnerability of urban populations.

Adding to the vulnerability of urban areas is the fact that they are complex systems that pose management challenges in terms of the interplay between people, infrastructure, institutions and environmental processes (Matthias and Coelho, 2007). Alterations to any of these components of the urban system could bring about changes in vulnerability. In this respect, politico-economic factors may be extremely important such that politically motivated decisions to spread costs, concentrate economic benefits and hide the real risks could increase vulnerability to extreme climate events substantially (Freudenberg et al., 2008). Further many factors affect urban environmental quality, hence contrasting trends in water and air quality are found for many of the worlds major cities (Duhn et al., 2008).

In hydrological terms urban areas are impermeable, channelize water rapidly and are often the sites of devastating flash floods. As urban areas expand the percentage coverage of impervious surfaces will also increase thus increasing the likelihood of flood events, sewerage surcharging, basement flooding and combined sewer overflow due to rapid runoff response following intense rainfall events (Nie et al., 2009). The pressure for urban areas to also expand onto flood plains and coastal strips will also result in an increase in exposure of populations to riverine (Feyen et al., 2009) and coastal flood risk. In the case of riverine floods, or indeed any climate related hazard, a trend to anincreasing reliance on engineered protective measures may also amplify vulnerability leading to "floods of folly" (Freudenberg et al., 2008). Similarly the continued reliance on insurance products as an adaptive strategy for managing flood risk or any other climate related hazard for that matter, may lead to complacency amongst individuals and communities such that subsidised insurance may create a moral hazard in addition to that of the physical climate hazard resulting in a higher level of vulnerability than otherwise would exist. Consequently insurance related strategies put in place to increase adaptive capacity may be offset by behaviour that increases exposure (Lamond et al., 2009; McLemand and Smit, 2006).

During the day urban areas absorb a large amount of the incoming energy from the sun, which is stored in the urban fabric and in the evening released back into the atmosphere in the form of heat. The consequence of this is the development of the so- called urban heat island which manifests itself in terms of higher nocturnal urban compared to surrounding rural temperatures. In large cities the urban heat island effect can result in temperatures being as much as 7-10^{o}C higher than nearby rural areas. As urban areas expand and also increase in density over the coming decades, urban heat is likely to become a serious issue not only for human health but for urban based ecosystem services the consequence of which will be increases in vulnerability to heat related health problems, urban drought and subsidence and effects from pests and diseases. For a number of major cities there is strong observational evidence for increases in urban warming (Fujibe, 2009; Kataoka et al., 2009; Stone 2007) which makes some of the posited changes to urban environmental quality and thus vulnerability and exposure a real prospect. Loss of urban green space through the process of urbanisation may also increase vulnerability to climate change in urban areas through decreasing runoff amelioration, urban heat island mitigation effects and biodiversity (Wilby and Perry, 2006). For some cities there is clear evidence of a recent trend to a loss of green space (Boentje and Blinnikov, 2007; Rafiee et al., 2009; Sanli et al., 2008) for a variety of reasons including planned and unplanned urbanization with the latter driven by internal and external migration resulting in the expansion of informal settlements.

A further source of vulnerability for urban areas is that as attempts are made to localise global climate science to small-scale urban situations, potential misinterpretations or misapplications of climate science and therefore mal-formed policies could increase the vulnerability of urban areas to extreme climate events. The same of course applies to non-urban areas, however relatively speaking, because of the concentrations of people in urban areas the consequences of non-legitimate and –accountable decisions (Coburn, 2009) may have greater impacts on vulnerability in urban compared with non-urban areas.

Increases in the number and extent of informal settlements or slums (UN Habitat, 2003; Utzinger and Keiser, 2006) which are often located on land exposed to a variety of geophysical hazards within or on the edge of rapidly expanding cities, poses potential problems. This is because inhabitants of urban slums are often socio-economically marginalized and characterized by poor health (Sclar et al., 2005) and livelihood insecurity (Kantor and Nair, 2005) making them particularly vulnerable to extreme events

2.7.3. Environmental Dimensions

The environment provides a range of ecosystem services. These can be classed as provisioning (e.g. food and water), regulating (flood and disease control), supporting (e.g. biogeochemical cycling) and cultural (e.g. aesthetic, spiritual and recreational). Clearly environmental degradation will have a major impact on the quality and availability of such services the effects of which are likely to be fundamental changes in the components of vulnerability such as increases in exposure to hazards through for example changes in flood occurrence (loss of regulation services) and altering sensitivity of populations for example via soil nutrient loss (loss of support services) and associated impacts on food production (loss of provision services).

Because the environment provides a resource base for human development any degradation of that resource will inevitably have an impact on development trajectories and society's vulnerability to extreme climate events. As a large proportion of the world's population depends on forestry, fishing and agriculture as a source of income natural or anthropogenic related changes to water, forestry, land and fishery resources will have a fundamental impact on human livelihoods and economies at a range of scales which will in turn translate into fundamental shifts in the vulnerability profiles of those most affected.

There are a number of current environmental trends that threaten human well-being and thus by extension human vulnerability (UNEP, 2007). For example climate variability and change is having marked impacts on human health, food production, security and resource availability. Many communities have suffered considerable losses due to extreme weather events, which have rendered them even more vulnerable to future climatic and non-climatic extreme events. Deterioration in both indoor and outdoor air quality continues to bring about premature mortality in many of the worlds largest cities or where indoor cooking over open fires is still commonplace. Agricultural productivity, food security, livelihoods and health are being affected by land degradation which often starts with soil sealing, erosion, salinization, fire risk, over production, and land fragmentation resulting from both natural and human attributable changes in climate, soil, vegetation conditions and economic and population pressures (Salvati and Zitti, 2009). The inability of many to secure safe water supplies is having fundamental impacts on human health and economic activities. Reductions in fish stocks because of over exploitation and coastal and marine pollution are jeopardizing livelihoods and health in those communities heavily dependent on marine resources for development. Species extinctions and loss of biodiversity pose a threat to the diminution of genetic pools that represent possible sources for future advances in medicine and agricultural production.

Archetypes of vulnerability which are specific, representative patterns of the interaction between environmental change and human well-being (Wonink et al., 2005; UNEP, 2007) provide a useful framework for considering how changes in vulnerability may accrue from environmental degradation. A number of archetypes of vulnerability may be identified including contaminated sites, dry lands, global commons, securing energy, small island developing states, technological approaches to water problems and urbanisation of the coastal fringes (UNEP, 2007). The ways in which these archetypes of vulnerability can affect human well being is summarised in Table 2-5 along with possible policy responses for reducing vulnerability and the types of extreme climate events (ECE) which are likely to impact vulnerability in an acute (short-term) and possible chronic (long-term) sense.

[INSERT TABLE 2-5 HERE
Table 2-5: Vulnerability archetypes, human well-being issues, responses, and extreme climate events (modified from UNEP, 2007).]

From the above it is clear that environmental degradation and poorly planned development may well increase vulnerability to extreme climate events. Further as vulnerability is determined by multiple stresses and a lack of societal options at a variety of levels any changes in the natural resource base through environmental deterioration brought about by natural causes or inappropriate development will have fundamental impacts on societies that have little protection against extreme climate events. Future trends in vulnerability related to environmental quality will also depend on trends in exported or imported vulnerability. In the case of the former the consumption of high value products in the developed world, which have been produced from resources in the developing world, may have important impacts on environmental quality where resource extraction has occurred. Similarly the competition for resources between adjacent rural and urban communities can result in the export of vulnerability form large cities to their increasing resource depleted hinterlands as might come about from the transfer of water from rural to urban areas. Vulnerability may be imported either through the outsourcing of industrial production to developing nations for both environmental and economic reasons or because of the importation of hazardous material for processing or storage in developing countries.

2.7.4. Economic Dimensions

Poverty is arguably one of the most pressing social issues facing humanity. As a determinant of vulnerability to extreme events, upward changes in poverty levels or the growth of globe's population classed as in poverty may well have a fundamental impact on general levels of vulnerability. Added to this is the additional stress climate change may add to populations living in poverty.

As noted by Erikson and O'Brien (2007) poverty and climate change are interlinked yet distinct. Accordingly it is important to recognise that adaptation measures need to specifically target climate change – poverty linkages as not all poverty reduction measures reduce vulnerability to climate change and vice versa. Further, measures beyond the local scale may be required as the drivers of poverty may necessitate that political and economic issues at a larger scale are tackled (Erikson and O'Brien, 2007; O'Brien et al., 2008). Because the determinants and dimensions of poverty are complex as well as its association with climate change (Demetriades and Esplen, 2008; Khandlhela and May, 2006; Hope, 2009), poverty related increases in vulnerability to extreme climate events could theoretically be obtained through changes in economic development and openness, geographical and demographical disadvantages, political regime characteristics and war, and social policy and human capital enhancement (Tsai, 2006).

2.7.5. Social Dimensions

2.7.5.1. Demography

Population growth, composition and distribution are fundamental factors in determining vulnerability. Rarely does the preparedness and response to extreme events have anything to do with the event magnitude itself. More often than not it is factors such as social class, education, gender, ethnicity or race, cultural background and language status that are important in determining vulnerability (Donner and Rodriguez, 2008).

Certain population groups may, in a relative sense, be more vulnerable than others. For example the very young and old are more vulnerable to heat hazards than other population groups (Staffogia et al., 2006) and therefore an aging population or rising birth rates may increase the pool of susceptible individuals and therefore societal vulnerability. Population growth due to inward migration may also influence vulnerability especially in urban areas where the inflow of economically disadvantaged people results in urban migrant communities locating in unplanned housing areas on marginal land. Therefore communities living in physically marginal situations such as on unstable valley side slopes (Nathan, 2008), in flood prone areas (Aragon-Durand, 2007; Bertoni, 2006; Colten, 2006; Douglas et al., 2008; Zahran et al., 2008) or marginally productive land, because of their economic circumstances, are more vulnerable than those living in areas where the likelihood of slope failure, flooding and soil erosion respectively is much reduced.

Over the next 10-20 years it is likely that migration will contribute significantly to population growth in a number of countries. Because of their disadvantaged position, in terms of social, economic and cultural capital, migrants may be more vulnerable to extreme climate events. The inability to understand extreme event related information, prioritisation of finding employment and housing and distrust of authorities will all contribute to increased vulnerability amongst migrant groups (Donner and Rodriguez, 2008; Enarson and Morrow, 2000).

The role of gender, race and class in determining vulnerability is widely debated but in general it would appear that poor minority women experience higher vulnerability because of inequalities which restrict their access to resources that could help modify their risk (Enarson and Fordham, 2001; Rodriguez and Russell, 2006).

2.7.5.2. Education

Environmental education programmes have been shown to promote resilience building in socio-ecological systems because of their role in enhancing biological diversity and ecosystem services. They also provide the opportunity to integrate diverse forms of knowledge and participatory processes in resource management (Krasny and Tidball, 2009). Given this the support of environmental education programmes through government funding at a variety of levels may play a critical role in the development of public levels of environmental awareness affecting people’s capability to take action towards sustainable development (Brieting and Wikenberg, 2010; Waktola, 2009). Because environmental education has clear benefits for increasing environmental awareness amongst children and adults (Kobori, 2009; Kuhar et al., 2010; Nomura, 2009; Patterson et al., 2009) support of this often funding sensitive aspect of education will be important for determining trends in the public understanding of some of the controlling factors of exposure and vulnerability related to extreme climate events.

2.7.5.3. Health and Well-Being

Individual and population health may determine broad levels of vulnerability and exposure to extreme events because good or poor health may influence the ability to respond to or cope with extreme events. Accordingly trends in the burden of disease and associated risk factors (Mather and Loncar, 2006) at a variety of geographical scales may affect local to global levels of vulnerability and exposure to extreme events. For example obesity, a risk factor for cardiovascular disease, has been noted to be on the increase in a number of countries (Skelton et al., 2009; Stamtakis et al., 2010). Such trends may well have an indirect impact on the vulnerability of people during periods of extreme events, as for example heat waves because pre-exisiting cardiovascular disease is a heat risk factor. Similarly observed and projected trends in major public health threats such as the infectious or communicable diseases HIV/AIDS, tuberculosis, and malaria could weaken the long term resilience of some populations. In addition to the diseases themselves, persistent and increasing obstacles to expanding or strengthening health systems such as inadequate human resources and poor hospital and laboratory infrastructure (Vitoria et al., 2009) may also contribute indirectly to increasing vulnerability and exposure in regions where for example malaria and HIV/Aids occasionally reach epidemic proportions.

Through its impact on key ecosystem services deteriorating environmental conditions (Tong et al., 2010) could exacerbate health related trends in vulnerability and exposure. For example land clearing and associated salinity increases could have implications for trends in wind-borne dust and respiratory health. However there is mixed evidence for trends in dust storm frequency (Goudie, 2009) and links between dust storm occurrence and respiratory health (Hong et al., 2009; Middelton et al., 2008). Altered ecology and increase in diseases may also follow land use change (Jardie et al., 2007) however the link between human induced changes to ecosystems and disease is complex (Ellis and Wilcox, 2009; Johnson et al., 2010; Ljung et al., 2009). Similarly the trends in the availability of clean drinking water, its impacts on the incidence of diarrhoeal disease (Clasen et al., 2007) and associated implications for health and resilience to other climate sensitive diseases may influence vulnerability and exposure.

2.7.6. Science and Technology

In many ways S&T is a double-edged sword in relation to vulnerability. It can help reduce vulnerability due to environmental and non-environmental change but on the other hand add to societal and environmental risk especially through contributing to environmental change.

Over the last few decades there have been rapid advancements in S&T especially in the agricultural sector. These have been functional in increasing food production, decreasing food prices and reducing famine. However a fundamental problem is that S&T developments and beneficiaries are unequal in distribution. This can lead to polarization of vulnerability over very short distances as for example brought about by the use of drought resistant crops in one area but not in a nearby area. To avoid such disparities clearly S&T transfer is required but the success of this will be very much dependent on the ability of the recipient community to apply the transferred S&T successfully. As opposed to complete reliance on technocratic solutions to vulnerability, blending western S&T with indigenous knowledge (Mercer et al., 2010) and ecological cautiousness offers opportunities for reducing vulnerability through the creation of eco-technologies with a pro-nature, pro-poor and pro-women orientation (Kesavan and Swaminathan, 2006).

Modern weather and forecasting techniques have helped reduce disaster risk and thus vulnerability through providing the basis for early warning for a range of ECE. Some forecasts are tailored for specific ECE such as hurricances or heat waves. However the efficacy of such early warning systems is very much dependent on the existence of well planned and thought through operationalisable response strategies. Notwithstanding this there is an increasing use of weather and climate information for planning and climate risk management (Changnon and Changnon, 2010) as well as the use of technology for the development of a range of decision support tools for climate related disaster management (van de Walle and Turoff, 2007).

Over reliance on S&T solutions as an adaptive option for coping with ECE and thus reducing vulnerability can in some cases be counterproductive (Marshall and Picou, 2008) as seen in the case of levee failure during Hurricane Katrina leading to what Freudenberg et al., (2008) have referred to as “floods of folly”. Further the persistent technocratic approach to hazards in general by the science and engineering community has tended to promulgate the view amongst the public and decision-makers that S&T solutions are the panacea for natural hazard management. This tends to stultify attempts to implement alternative approaches to vulnerability reduction through community empowerment to achieve hazard mitigation and the development of grass roots response strategies and coping mechanisms (Haque and Etkin, 2007).

2.7.7. Access to Information

Access to information related to early warnings, response strategies, coping mechanisms, S&T, human, social and financial capital is critical for reduction of vulnerability and increase resilience. A range of factors may control or influence the access to information including economic status, race (Spence et al., 2007), trust (Longstaff and Yang, 2008), belonging to a social network (Peguero, 2006) digital inequalities (Crutcher and Zook, 2009; Rideout, 2003). Further trends in the use of the internet for gathering information appear to be conditioned on a number of factors (Buente and Robbin, 2008).

Traditionally the approach to adaptation has been one focused on engineering or technology based solutions. However there is mounting evidence that non-structural interventions offer mutually beneficial interventions for adaptation. Integrating governance across all levels and sectors through for example incorporation of knowledge from the local to global in environment policies (Karlsson, 2007), co-management and involvement of stakeholders from all sectors in the management of natural resources (McConnell, 2008; Plummer 2006) and mainstreaming attention to vulnerability through policy can assist with understanding and addressing vulnerability. However the challenges associated with multi-level governance and co-management need to be recognized and can at times pose a barrier to achieving reduction in vulnerability (Armitage et al., 2007; Sandstrom, 2009). Environmental change and extreme events pose challenges to ecosystem services and thus human health. Accordingly prospective approaches to adaptation need to recognize the close association between environment and human well-being, as good levels of human health not only have implications for coping capacity and resilience but are crucial for development (Suhrcke et al., 2007).

Resolving conflict, though a challenge, could provide benefits for vulnerability reduction because war exacts a heavy toll on people thus affecting societal capacity to adapt and brings about damage to the environment. Although there are a variety of reasons for conflict, understanding the role of the competition for environmental resources and climate change in conflict generation (Barnett and Adger, 2007) could provide for developing policies for environmental cooperation that might facilitate vulnerability reduction, abatement of assaults on human well-being and create opportunities for development and poverty reduction.

Much environmental decision-making is non-inclusive especially as it relates to local resource users. This often generates tension between local and national level institutions because of contrasting visions of natural resource use. The inclusion of local concerns has the potential to transition local resource users from consumers of policies to agents in the making and shaping of the policies that affect their lives (Cornwall and Gaventa, 2000) leading to greater equity in financial and resource receipt (Leach et al., 2002) and thus reduced vulnerability due to marginalisation and social and economic disparity (Toni and Holanda, 2008).

Imperative for the attainment of sustainable livelihoods is the achievement of secure entitlements to natural resources (Whitford et al., 2010) as this can assist with poverty and thus vulnerability reduction. Further because of the role women play in managing natural resources in many countries addressing women's tenure rights can have positive effects in terms of ameliorating vulnerability (Flintan, 2010). Decision-making in the absence of knowledge can often lead to unfortunate outcomes. Accordingly building knowledge about environmental risk at a variety of levels, especially amongst vulnerable groups can assist with enhancing risk management and coping capacity. Also acknowledging reciprocity in knowledge generation and transfer is key to effective environmental decisionmaking as it relates to adaptation and coping strategies. Central is also the role of education in equipping the vulnerable with knowledge and actions that will assist with response and adaptation to extreme events (Cutter et al., 2006).

Although the potential exists for developments in science and technology, such as early warning systems, environmental monitoring and advances in risk assessment to reduce vulnerability, it is often difficult for those who stand to benefit most to access such developments. Localising S&T developments in terms of participation and relevance stands to enhance the achievement of the theoretical benefits of S&T. Globalisation, production and consumption often lead to the export or import of vulnerability. To manage such vulnerability institutions, sectors and individuals will need to develop cultures of responsibility and work to understand the chain of events that lead to vulnerability export/import with the result that actions can be taken and vulnerabilities of recipient communities can be reduced.

Without implementation, corrective and prospective plans of action for adaptation will remain as theoretical ideas at best. To achieve implementation the complexities underlying failure need to be understood so that these can be avoided. Building capacity for implementation by providing institutions with mandates and funding for action and monitoring the outcome of adaptation action plans will be critical if efficacy of corrective and prospective adaptation interventions is to be obtained at a variety of scales.

2.7.8. Influence of Gradual Climate Change

Climate change is expected to result in an increase in the climatology (timing, intensity, spatial extent) of extreme climate events and sea level rise. As outlined in Chapter 3 there has been an observed increase in the frequency of heat waves, intense rainfall, storminess, and storm surge for some regions of the world. Such observations are in line with climate change projections of extreme climate events. Observational evidence of increases in some extreme climate events however does not exist (e.g. tornadoes, thunderstorms, floods). Notwithstanding this climate change projections suggest that some events, such as heat waves and intense rainfall, will increase not only in their frequency but severity.

Following the definition of vulnerability adopted in this report, extreme climate events comprise an important element of exposure. Therefore current and predicted trends in extremes are likely to increase exposure and thus vulnerability in the absence of improvements in human well-being, investment in human and social capital and a reduction in human related environmental degradation. Exposure will not only potentially increase in endemic hazard areas and seasons but most likely in emerging climate hazard areas and seasons as a result of changes in storm tracks and the duration of storm seasons, the expansion of regions and periods of drought and extreme heat events, the intensification and alteration of the timing of hydrological cycle processes leading to intense rainfall events and changing periods of seasonal flood and low flow patterns. Observed and projected changes in the climatology of extreme events will therefore add to the changing spatial and temporal dynamics of exposure and thus vulnerability all other things being equal. Such changes through altering exposure will have a direct impact on vulnerability. Gradual climate change could also have a number of indirect impacts on vulnerability by altering the non-exposure terms of vulnerability. For example climate change may have a fundamental impact on the number of people in poverty or suffering from food and water insecurity, the social segregation of society, diminishing human and social capital, general health levels especially amongst the poor, where people live, conflict and governance. In short gradual climate change has the potential to add significantly to the multiple stressors that comprise vulnerability.

2.8. Risk Identification and Assessment

Risk accumulation, dynamic changes in vulnerabilities, and different phases of crises and disaster situations constitute a complex environment for identifying and assessing risks and vulnerabilities, risk reduction measures and adaptation strategies. In the context of climate change, risk identification, vulnerability assessment and improvement of our understanding of extreme events and disasters are pre-requisites for the development of adaptation strategies.

2.8.1. Risk Identification

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The modern vision of disaster risk management involves four distinct public policies or components:

- Risk identification (involving individual perception, social interpretation, and objective evaluation of risk)
- Risk reduction (which involves prevention or mitigation of physical and social vulnerability as such)
- Risk transfer (related to financial protection and in public investment)
- Disaster management (related to preparedness, warnings, response, rehabilitation and reconstruction after disasters).

It is easy to see from this perspective that the first three actions are *ex ante*; i.e. they take place in advance of disaster, and the fourth refers to *ex post* actions. At the same time, and inevitably, disaster risk management is transverse to development and a range of stakeholders and actors in society are necessarily involved in the process (Cardona 2004, 2010; IDB 2007). Clearly risk identification, through risk understanding by the stakeholders and actors and by vulnerability and risk assessment, is the first step for risk reduction, prevention and transfer, as well as climate adaptation in the context of extremes.

2.8.1. Risk Identification

Understanding risk factors and communicating risks, due to climate change, to decision makers and the general public are key challenges, especially for science. It requires, on the one hand, an improved understanding of risk factors, underlying vulnerabilities and societal coping and response capacities and, on the other hand, new formats of communication in terms of dealing with uncertainty and complexity – understood here as non-linearity, emergent structures and limits of knowledge (see e.g. ICSU-LAC, 2010, p. 15; Birkmann *et al.* 2009; Renn 2008, pp. 289; Bohle and Glade 2008, Patt *et al.,* 2005). The promotion of a higher level of risk awareness, regarding climate change-induced hazards and changes, also requires an improved understanding of the specific risk perceptions of different social groups, including those factors that influence and determine these risk perceptions, such as beliefs, values and norms.

Overall, essential pre-requisites for promoting a culture of adaptation and resilience are appropriate information and knowledge. Specific information and knowledge must first be collected on the dynamic interactions of exposed and vulnerable elements, e.g. persons, their livelihoods and critical infrastructures, and potentially damaging events, such as extreme weather events or potential irreversible changes as sea level rise. Based on the expertise of disaster risk research and findings in the climate change and climate change adaptation community, requirements for risk understanding related to climate change and extreme events particularly encompass:

- Knowledge of the processes by which persons, property, infrastructure, goods and the environment itself are exposed to potentially damaging events, e.g. understanding exposure in its spatial and temporal dimensions
- Knowledge of the factors and processes which determine or contribute to the vulnerability of persons and their livelihoods or of socio-ecological systems. Understanding increases or decreases in susceptibility and response capacity, including the distribution of socio- and economic resources that make people more vulnerable or that increase their level of resilience is also key
- Knowledge on how climate change impacts are transformed into hazards, particularly regarding processes by which human activities in the natural environment or changes in socio-ecological systems lead to the creation of new hazards (e.g. Natural-technical hazards, NaTech), irreversible changes or increasing probabilities of hazard events occurrence
- Knowledge regarding different tools, methodologies and sources of knowledge (e.g. expert knowledge / scientific knowledge, local or indigenous knowledge) that allow capturing new hazards, risk and vulnerability profiles, as well as risk perceptions. In this context, new tools and methodologies are also needed that allow for the evaluation e.g. of new risks (sea level rise) and of current adaptation strategies
- Knowledge on how risks and vulnerabilities can be modified and reconfigured through forms of governance, particularly risk governance – encompassing formal and informal rule systems and actor-networks at various levels. Furthermore, it is essential to improve knowledge on how to promote adaptive governance within the framework of risk assessment and risk management.

(ICSU-LAC, 2010, p. 15; Birkmann *et al.* 2009, Birkmann *et al.* 2008; Cutter and Finch 2008, Renn 2008, pp. 289; Bohle and Glade 2008; Biermann *et al*., 2007, Biermann *et al.* 2009, Füssel 2007; Renn and Graham 2006; Patt *et al.,* 2005; Cardona *et al.* 2005; and Kasperson *et al.* 2005)

Consequently, improving our understanding of disaster risk, in the context of climate change, and respective information needs for sustainable adaptation encompasses at least six knowledge demands:

- Identification of new hazards and irreversible changes
- Vulnerability patterns
- Risk perception and risk construction processes (particularly regarding 'unexperienced' hazards such as sea level rise)
- Evaluation and assessment methodologies and tools
- Risk communication
- Risk and adaptive governance.

If science is to help support the transition to a more sustainable and adaptive development in the light of climate change, with increasing frequency of extreme events and continuing creeping environmental degradation, risk identification and assessment are key activities. Climate change mitigation is a core task; however, it is increasingly evident that climate change can no longer be avoided and that existing green-house-gases in the atmosphere will imply a further increase in the probability of extreme weather events. Consequently, disaster risk understanding, communication and reduction in the context of climate change adaptation are crucial tasks (van Sluis and van Aalst 2006; ICSU-LAC 2010).

2.8.2. Vulnerability and Risk Assessment

Risk analysis and risk assessment were already issues of interest in Babylonian times. The development of modern risk analysis and assessments were closely linked to the establishment of scientific methodologies for identifying causal links between adverse health effects and different types of hazardous events and the mathematical theories of probability (Covello and Mumpower, 1985). Today, risk and vulnerability assessments encompass various approaches and disciplines and thus constitute a broad and multidisciplinary research field. In this regard, vulnerability and risk assessments can have different functions and goals.

Risk, as well as vulnerability assessment, is conducted from different angles depending on the underlying understanding of the terms. In this context, two main schools of thought can be differentiated. The first school of thought defines risk as a decision by an individual or a group to act in such a way that the outcome of these decisions can be harmful (Luhmann 2003; Dikau and Pohl 2007). In contrast, the disaster risk research community views risk as the product of the interaction of a potentially damaging event and the vulnerable conditions of a society or element exposed (UN/ISDR 2004).

Today, vulnerability and risk assessment encompass various approaches and techniques ranging from indicator-based global or national assessments to qualitative participatory approaches of vulnerability and risk assessment at the local level (see IDEA, 2005; Cardona, 2006; Birkmann, 2006a; Wisner, 2006a; IFRC, 2008; Dilley, 2006; and Peduzzi *et al.,* 2009).

In general terms, vulnerability and particularly risk assessment can be defined as a process to comprehend the nature of risk and to determine the level of risk (ISO 31000). Additionally, communication within the assessment and risk management are seen as key elements of the process (Renn, 2008). More specifically, vulnerability and risk assessment deal with the identification of different facets and factors of vulnerability and risk, by means of gathering and systematising data and information, in order to be able to identify and evaluate different levels of vulnerability and risk of societies -social groups and infrastructures- or coupled socio-ecological systems at risk. A common goal of vulnerability and risk assessment approaches is to provide information about profiles, patterns of and changes in risk and vulnerability (see e.g. IFRC, 2008; Birkmann, 2006a; IDEA, 2005; Cardona *et al.,* 2005), in order to define priorities, select alternative strategies or to formulate new response strategies. In this context, the Hyogo Framework for Action stresses that the starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and of the ways in which hazards and vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge (UN, 2005).

One of the key strategic activities of disaster risk management and adaptation is the vulnerability and risk assessment, which requires the use of reliable methodologies that allow an adequate estimation and quantification of potential losses and consequences to the human systems in a given exposure time.

There are a wide range of approaches for integrating data and modelling risk and vulnerability. *Inductive* approaches model risk through weighting and combining different hazard, vulnerability and risk reduction variables. *Deductive* approaches are based on the modelling of historical patterns of materialized risk (i.e. disasters, or damage and loss that have already occurred). Other approaches combine the results of inductive and deductive modelling. An obstacle to inductive modelling is the lack of accepted procedures for assigning values and weights to the different vulnerability and hazard factors that contribute to risk. Deductive modelling will not accurately reflect risk in contexts where disasters occur infrequently or where historical data are not available. In spite of this weakness, deductive modelling offers a short cut to risk indexing in many contexts and can be used to validate the results from inductive models (Maskrey 1998).

Probabilistic estimations of risk attempt to predict damage or losses even where insufficient data are available on the system being analyzed. Failure and event trees are used for the analysis, and the probability of damage is evaluated in systematic fashion. This type of approach is useful for detecting deficiencies and for improving security levels in complex systems. The actuarial approach represents a classic example of *objectivist* approaches to the analysis of risk, where the base unit is an expected value that corresponds to the relative frequency of an average event in time (UNDRO, 1980; Fournier d'Albe, 1985; Petrovsky and Milutinoviç, 1986; Coburn and Spence, 1992; Woo, 1999; Grossi and Kunreuther, 2005; Cardona *et al.,* 2008a/b; Cardona 2010).

From an objectivist point of view, to achieve the overall goal of identifying and quantifying disaster risk, it is necessary to use and even develop a method that takes account the natural hazards in an integrated manner that includes the total and detailed exposure of assets with their main features. This in order to take into account the specific vulnerability of each component and to evaluate risk assessment using an appropriate technique that takes into account the uncertainty of the process, the inevitable limitations on information. In most cases it is necessary to use certain approaches and criteria for simplification and for aggregation of information due to a lack of data or the inherent low resolution of the information. This fact sometimes means sacrificing some scientific or technical and econometric characteristics, accuracy and completeness that are desirable features when the risk evaluation is the goal of the process (Cardona *et al.,* 2003).

The risk estimate must be prospective, anticipating scientifically possible hazard events that may occur in the future. For the case of hurricane-winds, the hydrometeorologic information available of the historic hurricanes that have affected the area of study is used and, jointly with engineering methodologies, the effects of these phenomena upon the exposed assets are estimated. Due to the high uncertainties inherent to the models of analysis regarding the severity and frequency of occurrence of the events, the risk model is based on probabilistic formulations incorporating said uncertainty in the risk evaluation. The steps of risk assessment from an objectivist point of view are can be described as follows:

- *Hazard assessment*: This means calculating the threat associated to all possible extreme events that could occur, to a group of selected events, or even to a single relevant event. For each type of extreme event it is possible to calculate the probable maximum value of the intensity that characterized for different rates of occurrence or return period.
- *Exposure modeling*: This is the description of the exposed elements or assets that may be affected by the extreme events or hazards.
- *Vulnerability evaluation*: The assignment of the vulnerability functions to each exposed element located in the hazard prone area.
- *Risk assessment*: It is the convolution of the hazard with the vulnerability of the exposed elements in order to assess the potential impact or consequences. Risk can be expressed in terms of damage or physical effects.

Once the expected physical damage has been estimated (average potential value and its dispersion) as a percentage for each of the assets or components included in the analysis, it is possible estimating various parameters or metrics as result of obtaining the Loss Exceedance Curve, such as the Probable Maximum Loss for different return periods and the Average Annual Loss or technical risk premium. These measures are of particular importance for the stratification of risk and the design of disaster risk intervention strategy considering risk reduction, prevention and transfer (Woo, 1999, Grossi and Kunreuther, 2005, Cardona *et al.,* 2008a/b).

At present probabilistic risk assessment is the result of the evolution from early days of insurance to computer-based catastrophe modelling using advanced information technology and geographic information systems (GIS) for mapping. With the ability to store and manage vast amount of information, GIS became an ideal environment for conducting easier and more cost-effective hazard and loss studies (Maskrey, 1998; Grossi and Kunreuther, 2005).

On the other hand, vulnerability and risk *indicators* or *indices* are feasible techniques for risk monitoring and may take into account both the harder aspects of risk as well as its softer aspects (Cardona *et al.,* 2003; Cardona, 2006;

IDEA, 2005). The usefulness of indicators depends on how they are employed. The way in which indicators are used to produce a diagnosis has various implications. The first relates to the structuring of the theoretical model. The second refers to the way risk management objectives and goals are decided on. This aspect is important given that it is preferable to promote an understanding of reality not in strict terms of the ends to be pursued, but, rather, in terms of the identification of a range of possibilities, information on which is critical to organize and orientate the praxis of effective intervention (Zemelman 1989). An appropriate technique based on indicators can be a rational benchmark or a common metric to rule the risk variables from a control point of view (Carreño *et al.,* 2007b, 2009). The goal in this case is not to reveal the truth, but rather to provide information and analyses that can improve decisions.

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Box 2-4. The Disaster Deficit Index: A Metric for Sovereign Fiscal Vulnerability Assessment.

Future disasters are contingency liabilities that must be included in the balance of each nation. As pension liabilities or guaranties that the government has to assume for the credit of territorial entities or due to grants, disaster reposition costs are liabilities that become materialized when the hazard events occur. By other way, extreme impacts can generate financial deficit due to sudden an elevated need of resources to restore affected inventories or capital stock (Cardona et al 2007, 2010; Carreño et al 2010). The Disaster Deficit Index (DDI) developed in the framework of the Program of Indicators of Disaster Risk and Risk Management for the Americas of the Inter-American Development Bank (Cardona 2005, 2010; IDEA, 2005) provides an estimation of the extreme impact (due to hurricane, floods, tsunami, earthquake, etc.) during a given exposure time and the financial ability to cope with such situation. The DDI captures the relationship between the loss that the country could experience when an extreme impact occurs (demand for contingent resources) and the public sector's economic resilience; that is, the availability of funds to address the situation (restoring affected inventories). This macroeconomic risk metric underscores the relationship between extreme impacts and the capacity to cope of the government. Figures 2-5 and 2-6 show the DDI for 2009 and for the last four periods.

[INSERT FIGURE 2-5 HERE:
Figure 2-5: Disaster Deficit Index (DDI) and Probable Maximum Loss in 500 Years for 2008.]

[INSERT FIGURE 2-6 HERE:
Figure 2-6: Disaster Deficit Index (DDI) (500 years) for 19 countries of the Americas.]

A DDI greater than 1.0 reflects the country's inability to cope with extreme disasters even by going into as much debt as possible. The greater the DDI, the greater the gap between losses and the country's ability to face them. This disaster risk figure is interested and useful for a Ministry of Finance and Economics. It is related to the potential financial sustainability problem of the country regarding the potential disasters. On the other hand, the DDI gives a compressed picture of the fiscal vulnerability of the country due to extreme impacts. The DDI has been a guide for economic risk management; the results at national and subnational levels can be studied by economic, financial and planning analysts who can evaluate the budget problem and the need to take into account these figures in the financial planning.

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It is important to recognise that complex systems involve multiple facets (physical, social, cultural, economic and environmental) that are not likely to be measured in the same manner. Physical or material reality have a harder topology that allows the use of quantitative measure, whilst collective and historical reality have a softer topology in which the majority of the qualities are described in qualitative terms (Munda, 2000). These aspects indicate that a weighing or measurement of risk involves the integration of diverse disciplinary perspectives. An integrated and interdisciplinary focus can more consistently take into account the non-linear relations of the parameters, the context, complexity and dynamics of social and environmental systems, and contribute to more effective risk management by the different stakeholders involved in risk reduction decision-making. It permits the follow-up of the risk situation and the effectiveness of the prevention and mitigation measures can be easily achieved. Results can be verified and the mitigation priorities can be established with regard to the prevention and planning actions to modify those conditions having a greater influence on risk (Carreño *et al.,* 2007a, 2009).

In order to ensure that risk and vulnerability assessments are also understood, the key challenges for future vulnerability and risk assessments, in the context of climate change, are, in particular, the promotion of more integrative and holistic approaches, the improvement of assessment methodologies and the need to address the requirements of decision makers and the general public.

Many concepts and assessments still focus solely on one dimension, such as economic risk and vulnerability. Thus, they consider a very limited set of vulnerability factors and dimensions. Some approaches, for example, at the global level, view vulnerability primarily with regard to the degree of experienced loss of life and economic damage (see Dilley *et al*. 2005; and Dilley 2006). In contrast, approaches providing a more integrative and holistic perspective capture a greater range of dimensions and factors of vulnerability and disaster risk. Successful adaptation to climate change has been based on a multi-dimensional perspective, encompassing e.g. social, economic, environmental and institutional aspects. Hence, risk and vulnerability assessments – that intend to inform these adaptation strategies – require also a multi-dimensional perspective.

Assessment frameworks with an integrative and holistic perspective were developed by Turner *et al*. (2003) and Birkmann (2006b) – based on Bogardi/Birkmann (2004) and Cardona *et al*. (2005). Despite differences between the frameworks mentioned above, it is interesting to note that a common characteristic is the conceptualisation of vulnerability and risk within the context of general system theory, considering various linkages and feedback processes (feedback loops) between different factors or components of risk and vulnerability. Furthermore, integrative and holistic approaches disaggregate vulnerability into at least three factors: a) exposure, b) sensitivity, susceptibility or fragilities (inner conditions of the exposed elements) and c) response capacities (coping or adjustment) or the lack of it (lack of resilience) (see Cardona and Barbat, 2000; Turner *et al.,* 2003; Birkmann, 2006b; Carreño *et al.,* 2009).

Hence, the assessment of vulnerability and risk does not solely focus on the potential outcome, for example a certain level of risk, but rather helps to understand interlinkages between factors that might influence and determine the vulnerability and risk. Additionally, integrated assessment frameworks also take into account various thematic dimensions of vulnerability. These range from economic, socio-economic, environmental, cultural to institutional aspects. Thus these assessments require an interdisciplinary perspective that considers the broader context in which disaster risk is embedded.

Additionally, Turner *et al*. (2003) underline the need to focus on different scales simultaneously, in order to capture the interlinkages between different scales and their impact on the vulnerability of the exposed human-environmental system. However, the influences and interlinkages between different scales are still difficult to capture, especially due to their dynamic nature and their potential reconfiguration during and after disasters, for example, in form of external disaster aid.

Furthermore, integrative frameworks based on the notion of coupled systems and feedback loop systems also encompass the evaluation of response and feedback processes. Key elements of a more integrative and holistic view on risk and vulnerability are the identification of causal linkages between select factors of vulnerability and risk and the potential interventions that nations, societies or different social groups or individuals have to reduce their vulnerability or exposure to risks. The integration of these feedback processes and intervention tools within the assessment also promotes a problem solving perspective in the way that they put emphasis on the identification of policy responses (formal and informal responses) and options on how to reduce vulnerability and risk levels (Cardona, 1999; Cardona and Hurtado, 2000a/b; Cardona and Barbat, 2000; Turner *et al.,* 2003; IDEA 2005a/b; Birkmann, 2006b; Carreño *et al.,* 2005, 2009; ICSU-LAC 2010). Figure 2-1 contours a holistic and integrative perspective.

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Box 2-5. Measuring Vulnerability at National Level: The Prevalent Vulnerability Index.

Vulnerability is a key issue in understanding disaster risk. The Prevalent Vulnerability Index (PVI), developed in the framework of the Program of Indicators of Disaster Risk and Risk Management for the Americas of the Inter-American Development Bank (Cardona 2005, 2010; IDEA, 2005) provides a holistic approach to vulnerability assessment using social, economic and environmental indicators. The PVI depicts predominant vulnerability conditions. It provides a measure of direct effects (as result of exposure and susceptibility) as well as indirect and intangible effects of hazard events (as result of socioeconomic fragilities and lack of resilience). The indicators used are made up of a set of indicators that express situations, causes, susceptibilities, weaknesses or relative absences affecting the country, region or locality under study, and which would benefit from risk reduction actions. The indicators are identified based on figures, indices, existing rates or proportions derived from reliable databases available worldwide or in each country. These vulnerability conditions underscore the relationship between risk and development. Figures 2-7 and 2-8 show the aggregated PVI (Exposure, Social Fragility, Lack of Resilience) for 2007 and for the last four periods.

[INSERT FIGURE 2-7 HERE:
Figure 2-7: Aggregate Prevalent Vulnerability Index (PVI) for 2007.]

[INSERT FIGURE 2-8 HERE:
Figure 2-8: Prevalent Vulnerability Index (PVI) for 19 countries of the Americas.]

Vulnerability and therefore risk are the result of inadequate economic growth and deficiencies that may be corrected by means of adequate development processes. The information provided by an index such as the PVI should prove useful to ministries of housing and urban development, environment, agriculture, health and social welfare, economy and planning. The main advantage of PVI lies in its ability to disaggregate results and identify factors that should take priority in risk management actions as corrective and prospective measures or interventions of vulnerability from development point of view.

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Besides strengthening the integrative and holistic perspective within risk and vulnerability assessment, in the context of climate change, risk identification and vulnerability assessment has to be undertaken in different phases, e.g. before, during and even after disasters occur. Although risk and vulnerability reduction should be primarily conducted before potential disasters occur, it is important to acknowledge that ex-post and forensic studies of disasters provide a laboratory in which to study risk and disasters as well as vulnerabilities revealed (see ICSU-LAC, 2010; and Birkmann and Fernando, 2008). Disasters draw attention to how societies and socio-ecological processes are changing and acting in crises and catastrophic situations, particularly regarding the reconfiguration of access to different assets or the role of social networks and formal organisations (see Bohle, 2008). In this context, it is possible to evaluate actual disaster response processes and disaster relief and reconstruction activities and programmes, in terms of their contribution to medium- and long-term vulnerability and risk reduction as well as climate change adaptation. It is noteworthy that, until today, many post-disaster processes and strategies have failed to integrate aspects of climate change adaptation and long-term risk reduction (see Birkmann *et al.,* 2008, 2009).

In the broader context of the assessments and evaluations, it is also crucial to improve the different methodologies to measure and evaluate hazards, vulnerability and risks. The disaster risk research has paid more attention to sudden-onset hazards and disasters such as floods, droughts, storms, tsunamis, etc., and less on the measurement of creeping changes and integrating the issue of tipping points into these assessments. Therefore, the issue of measuring vulnerability and risk, in terms of quantitative and qualitative measures also remains a challenge. Lastly, the development of appropriate assessment indicators and evaluation criteria would also be strengthened, if respective goals for vulnerability reduction and climate change adaptation could be defined for specific regions, such as coastal, mountain or arid environments. Most assessments to-date have based their judgment and evaluation on a relative comparison of vulnerability levels between different social groups or regions.

The design of public policy on disaster risk management is very much related to the evaluation technique used to orient that policy. The quality of the evaluation technique, called by some as its scientific pedigree, has unsuspected influence on policy formulation. If the diagnosis invites action it is much more effective than where the results are limited to identifying the simple existence of weaknesses or failures.

The quality attributes of a risk model are represented by its *applicability*, *transparency*, *presentation,* and *legitimacy*. Respect for these attributes determines the *scientific pedigree* of a particular technique. Applicability refers to the way a model is adjusted to the evaluation problem at hand, to its reach and comprehensiveness, and the accessibility, aptitude, and level of confidence of the information required. Transparency is related to the way the problem is structured, facility of use, flexibility and adaptability, and to the level of intelligibility and comprehensiveness of the algorithm or model. Presentation relates to the transformation of the information, visualization, and understanding of the results. Finally, legitimacy is linked to the role of the analyst, control, comparison, the possibility of verification, and acceptance and consensus on the part of the evaluators and decision-makers.

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Box 2-6. Community-Based Climate Risk Assessment. [to be coordinated with chapter 5]

Examples of guidance on how to assess climate vulnerability at the community level, often with specific attention fo extreme weather and climate events, include Moench and Dixit, 2007; Van Aalst *et al.,* 2007; CARE, 2009; IISD *et al.*, 2009; Tearfund, 2009.

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Box 2-7. Risk Screening for Development Projects and Portfolios [to be coordinated with chapters 6 and 7]

A specific area of risk screening relates to development projects and portfolios. Several of these have paid specific attention to the risk of extremes (see e.g. Van Aalst and Burton, 1999, 2004; Klein, 2001; Klein *et al.,* 2007; Agrawala and van Aalst, 2008; Tanner, 2009).

_____ END BOX 2-7 HERE _____

2.8.3. Risk Perception and Communication

Risk and vulnerability are preconditions for the occurrence of future disasters (Birkmann, 2006a/b). Thus risk perception and understanding the nature of disasters requires more information and communication about vulnerability factors, dynamic temporal and spatial changes of vulnerability and the coping and response capacities of societies or social-ecological systems at risk (see Turner *et al*. 2003; Cardona *et al*. 2005; Birkmann, 2006b/c; Cutter/Finch 2008 and ICSU-LAC, 2010).

What are the key factors that determine how people perceive and respond to a specific risk is a key issue for risk management and climate change adaptation effectiveness. This is the reason why it is necessary to address how people indentify and assess risk (perception of risk, whether it is real or not) – and then how to communicate this assessment to various audiences. Risk communication is a complex cross-disciplinary field that involves reaching different audiences to make a risk comprehensible, understanding and respecting audience values, predicting the audience's response to the communication, and improving awareness and collective and individual decision making. Effectiveness of risk management is based on how planners use data to design more effective risk communication programs and what theories, models, tools, and good practices exist to serve as resources for risk communication. Risk managers and practitioners must understand the affective/emotional/instinctive ways people interpret risk information in order to anticipate and account for human behaviours in planning for, responding to, or recovering from harmful events.

_____ START BOX 2-8 HERE _____

Box 2-8. Lessons on Risk Perception and Communication from Early Warning Systems. [TBD]

_____ END BOX 2-8 HERE _____

2.9. Risk Accumulation and the Nature of Disasters

2.9.1. Risk Accumulation

In a disaster risk context, the notion of risk accumulation describes a gradual build-up of disaster risk in specific locations, often due to a combination of processes, some persistent and/or gradual, others more erratic, often in a combination of exacerbation of inequality, marginalisation and disaster risk over time. Other underlying factors may include a decline in the regulatory services provided by ecosystems, inadequate water management, land-use changes, rural–urban migration, unplanned urban growth, the expansion of informal settlements in low- lying areas and an under-investment in drainage infrastructure. The classic example is disaster risk in urban areas in many rapidly growing cities in developing countries. In these areas, disaster risk is often very unequally distributed, with the poor facing the highest risk, for instance because they live in the most hazard-prone parts of the city, often in unplanned dense settlements with a lack of public services; lack of waste disposal may lead to blocking of drains and increases the risk of disease outbreaks when floods occur; with limited political influence to ensure government interventions to reduce risk. The accumulation of disaster risk over time may be partly caused by a string of smaller disasters due to continued exposure to small day-to-day risks in urban areas (e.g. Pelling and Wisner, 2009), aggravated by limited resources to cope and recover from disasters when they occur; clearly creating a vicious cycle of poverty and disaster risk. Analysis of disaster loss data suggests that frequent low intensity losses often highlight an accumulation of risks which will be realized when an extreme hazard event occurs (UNISDR, 2009a).

Such patterns of risk accumulation are often most effectively addressed based on a local understanding of risks of all scales. This may include better collection of sub-national disaster data that allows visualization of complex patterns of local risk (UNDP, 2004), as well as locally owned processes of risk identification and reduction. For instance, Bull-Kamanga et al. (2003) suggests that for urban disaster risk in Africa, perhaps the most important aspect of risk reduction is to support to community processes amongst most of the vulnerable populations that identify risks and set priorities – both for community action and for action by external agencies (including local governments). Such local risk assessment processes also avoid the pitfalls of planning based on government maps which rapidly going out of date due to unplanned construction.

*[***UNDP Living With Risk page 26: “Risk accumulates before being released in a disaster*
Everyday hazards and vulnerability form patterns of accumulating risk that can culminate in disaster triggered by an extreme natural hazard event. Achieving MDG 1 (to eradicate extreme poverty and hunger) and MDG 7 (to ensure environmental sustainability) will have a direct impact on reducing human vulnerability to everyday hazards and the accumulation of risk that prepares the way for disaster.”]

2.9.2. The Nature of Disasters and Barriers to Overcome

This chapter has highlighted how risk is determined not just by hazards, but importantly also by vulnerability and exposure. A better understanding of risk, including vulnerability and exposure, is essential for adaptation strategies and practices. That understanding must include not only the determinants of risk that define the nature of disasters, but also the barriers to overcome to better manage risk. These barriers are systematic and deeply engrained in the structure of society, and may include inequality, governance challenges, and adverse incentives.

Sometimes disasters themselves can be windows of opportunity for addressing the determinants of disaster risk. Physically, to not reconstruct the same exposure and vulnerability that existed before the hazard materialized, for instance in buildings and infrastructure, or the location of key settlements; and more broadly to address the underlying drivers of risk, building on the public awareness and political momentum for risk reduction to enhance community risk awareness and preparedness and increase accountability of public institutions for future disaster risk. The growing attention for adaptation as a component of development planning, including disaster risk as an integral component of the overall climate risk to be addressed, may offer an important opportunity to rationally assess and address these risks without waiting for a disaster to happen to justify appropriate investments in risk reduction.

2.10. Research Gaps

In a climate change context, analysis of exposure and vulnerability as drivers of climate risk remains an overall research gap. There has been a strong emphasis on changing climate phenomena, including hazards that may result in disasters, and to some extent in identification of actual and potential impacts. By comparison, the attention for exposure and vulnerability as drivers of changing climate risk has been very limited, especially given their importance in identifying and implementing appropriate intervention strategies.

Specifically, from a policy perspective there is strong interest in the quantification of the relative importance of trends in hazard intensity or frequency compared to trends in exposure and vulnerability as drivers of changes in risk. Beyond the general statement that trends in exposure and vulnerability are the main cause for the observed increases in disaster occurrence, this desire is likely to remain elusive for most hazards for most areas given limitation in climate information and disaster data. Another more specific interest is the quantification of the feedback loop, i.e. how strongly gradual climate change and/or the impacts of more frequent or intense disasters result in rising exposure and higher vulnerability to future hazards.

Shifting towards research gaps oriented towards risk management practice, one methodological gap is the development and application of appropriate climate risk assessment methodologies at the local level that can be rolled-out at scale and made available to a wide range of stakeholders at the local level, particularly in developing countries. In that context, a key challenge remains to couple information gathered in local risk assessments, often at the level of a specific city or even community, to national and international assessments of risk. This includes qualitative assessments to inform appropriate policy and practice, as well as quantitative assessments (including indicators) to set priorities and measure progress.

Another area of research that is underexplored in many aspects of climate risk management is decision analysis (including explicit account of different perspectives among different stakeholders). Many decision-models focus on optimizing decision-making given specific climate information, whereas there is a clear need to particularly develop approaches that focus on robust decisions given an explicit awareness of the inherent unknowns (e.g. Dessai et al., 2009). Such a perspective on risk assessment also requires new approaches for risk communication, and much research is needed to better assess effectiveness of interventions to reduce vulnerability and exposure.

Finally, a cross-cutting research gap relates to assessment of systemic risks. The rising interdependence of economies means that local disasters can have causes and implications far beyond their direct area of occurrence. A key example in a disaster context is the 2007-2008 food crisis, which was almost entirely unpredicted. It was created by a combination of many factors, including droughts and rising oil – and thus transport and fertilizer -- prices, as well as increasing use of biofuels and changing demand, especially in Asia. Supply and demand were further complicated by an international system affected by price supports and subsidies, as well as speculation. This also highlights the need for better understanding (and anticipation) of distributional effects (for instance, crop failures in one area may benefit farmers elsewhere). Assessment challenges include model limitations, especially the fact that models often record past experience rather than providing a true upstream evaluation of future risk; the fact that models often assume more or less linar relationships from hazards to outcomes and are thus inadequate to predict complex phenomena inherent in systemic risks; the fact that long-term consequences tend to be neglected; and the fact that human behavior is often the prevailing risk factor, but relatively difficult to evaluate for a wide range of possible futures (OECD, 2003). Note that systemic analysis challenges may particularly include the interaction of natural disasters with other systemic phenomena, such as pandemics (avian influenza), commodity price fluctuations, or the global financial crisis.

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Table 2-1: *Definitions of the term vulnerability as described in the literature reviewed.*

Domain	**Definition of vulnerability**	**Author**
Risk (physical)	Vulnerability is defined as the susceptibility to cause damage from an event and ability to recover from the impacts of it.	(Montz and Evans, 2001)
	Vulnerability measures the potential for damage or loss that may be inflicted to population, infrastructure and business (hazard community).	(Papathoma and Dominey-Howes, 2003)
	Vulnerability is considered to be the degree of loss from the occurrence of a hazard of a given magnitude (hazard community).	(Pielke *et al.,* 2003)
	In the context of risk management vulnerability refers to an internal risk factor for an element or group of elements that are exposed to a hazard. Vulnerability reflects the intrinsic physical, economic, social and political predisposition or susceptibility of a community to be affected by or suffer adverse effects when impacted by a dangerous physical phenomenon of natural, socio-natural or anthropogenic origin. It also signifies the lack of resilience or capacity of the community to anticipate, cope and recover.	(Cardona *et al.,* 2003)
	Vulnerability is the potential to experience adverse impacts, a measure of the damage suffered by an element at risk when affected by a hazardous process or event.	(Galli and Guzzetti, 2007)
Climate change	Vulnerability is defined here as the degree to which human and environmental systems are likely to experience harm due to a perturbation or stress.	(Luers *et al.,* 2003)
	Vulnerability as the potential for loss and distinguish between social and biophysical vulnerability.	(Brklacich and Bohle, 2006)
	Vulnerability, as defined by the IPCC, is the “degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. It is a function of the climate-related stimuli to which a system is exposed, its sensitivity and its adaptive capacity”.	(IPCC, 2007)
	Vulnerability is the likelihood that a specific coupled human–environment system will experience harm from exposure to stresses associated with alterations of societies and the environment, accounting for the process of adaptation.	(Schröter *et al.,* 2005)
Social/institutional vulnerability	Vulnerability is related to marginalisation and is described by variables such as: class, gender, age, ethnicity, access to livelihoods and resources.	(Wisner, 1993)
	Vulnerability is the result of a number of factors that increase the chance that a community will be unable to deal with an emergency. Not all sections of a community are vulnerable to hazards, but most are vulnerable to some degree.	(WHO, 1999)
	Vulnerability as a composition of lack of preparedness, weakness in coping capacity, and shortage of resilience.	(Alcantara-Ayala, 2002)
	Vulnerability as the characteristic of a person and a group and their condition that influence their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard.	(Wisner *et al.,* 2004)
	Vulnerability is a condition that depends on primarily upon a society's social order and the relative position of advantage or disadvantage that a particular group occupies within it.	(Bankoff, 2004b)
	Vulnerability describes the condition of a population that is inadequately prepared to face an extreme event and unable to	(Cannon, 2006)

	recover without external assistance.	
	Vulnerability is the pre-event, inherent characteristics or qualities of social systems that create the potential for harm.	(Cutter *et al.,* 2008b)
Integrated view	Vulnerability is the degree of susceptibility and resilience of the community and environment to hazards. The degree of loss to a given element at risk or set of such elements resulting from the occurrence of a phenomenon of a given magnitude an expressed on a scale of 0 (no damage) to 1 (total loss)	(Buckle *et al.,* 2001)
	Vulnerability as the degree of fragility of a person, a group, a community or an area towards defined hazards. Vulnerability is a set of conditions and processes resulting from physical, social, economic and environmental factors that increase the susceptibility of a community to the impact of hazards. Vulnerability also encompasses the idea of response and coping, since it is determined by the potential of a community to react and withstand a disaster.	(Kumpulainen, 2006)
	Vulnerability is a condition resulting from physical, social, economic and environmental factors or processes that increase the susceptibility of a community to the impact of a hazard.	(Arakida, 2006)
	Vulnerability is seen as the outcome of a mixture of environmental, social, cultural, institutional, and economic structures, and processes related to poverty and (health) risk, not a phenomenon related to environmental risk only.	(Brouwer *et al.,* 2007)

Table 2-2: *People exposed to and killed in disasters in low and high human development countries, respectively, as a percentage of total number of people exposed to and killed by disasters. Source: Birkmann, 2006: 174 (after Peduzzi, 2005).*

	Average exposed per year	**Average killed per year**
Low Human Development Countries	11%	53%
High Human Development Countries	15%	1.8%

Table 2-3: *Differential exposure and vulnerability of identified groups*

Dimensions	**Characteristics**	**Sources**
Gender	a) Unequal gender relations arising from patriarchal structures (xxx) can create new vulnerabilities or worsen existing ones for women and girls. b) Access to social capital is gendered (xxx) although not always suggesting a negative or limiting effect (xxx). c) Men and women have different entitlements (access to resources (Sen 1981) and abilities to reduce their vulnerability through various coping and adaption practices d) Men may be more mobile and have more opportunities to use large blocks of time on a single pursuit (perhaps livelihood activities) while women generally cannot because of their range of reproductive duties e) Women are a heterogeneous group and cannot be assumed to be equally vulnerable, everywhere and all of the time f) Gender is a cross cutting issue which can qualify all vulnerability dimensions. g) gender should be understood as an inclusive term and not simply a binary one. Groups defined/self-defining as transgender or non heterosexual are particularly invisible and under-researched and may be particularly vulnerable because of that alone	a) b) xxx c) Sen 1981 d) Eriksen, Brown and Kelly, 2005: 300-301 e) Fordham, 1998, 1999, Fordham, 2003: 64-65; Enarson and Fordham, 2001; Peacock *et al*. 1997; Fothergill, 1996 f) ISDR Words Into Action g) Wisner LA transsexuals; Pincha transgender; Gailliard xxx
Age	In terms of age, it is often those at the extreme ends of the age range who are identified as vulnerable (see heat/cold wave examples above). Children are often at or near the top of any list of vulnerable groups (data on why: stage of physical, intellectual and emotional development; greater surface area: body mass ratio; general lack of power and agency; but examples of their exercise of agency and risk reduction actions and potential must also be acknowledged	(Jabry, 2002; Wisner, 2006b).
Children	In terms of risk groups, urban children in poverty face disproportionate risks from climate change. Children's vulnerability comes from their state of rapid development; their relative inability to deal with deprivation, stress and extreme events; their physiological immaturity; and their limited life experience. While urban children generally fare better than their rural children do, this is not the case for those living in extreme urban poverty. On the more positive side, children can also be very resilient to stresses and shocks but require adequate support and protection.	SHERIDAN BARTLETT Climate change and urban children: impacts and implications for adaptation in low- and middleincome countries Environment & Urbanization Vol 20(2): 501–519 2008
Race/Ethnicity/ Religious Associations (link to culture)	a) Hurricane Katrina – showing root causes of social vulnerability b) Evidence of differential access to relief (eg Moslems after Gujarat earthquake, other references)	a) references plus Cutter and Finch, 2008
Dis/ability		Mark Pelling contribution
Wealth/poverty	a) Vulnerability is not equal to poverty	a) Blaikie *et al*., 1994
Class/Caste	a) Guatemalan earthquake of 1976 termed a 'classquake'	a) O'Keefe *et al.,* 1976

Table 2-4: *Vulnerability indicators used in Collins and Bolin (2007)*

Indicator category	**Indicator Type**
Biophysical	
Groundwater access	Exempt wells overlying hard rock and outside of the basin-fill aquifer complex
Well spacing	Well density
Social	
Socio-demographic	
Population and structure	Total population Total housing units
Access to resources	Number of residents:owner/renters Number of female-headed households Number of people < age 18 Number of people > age 64
Socioeconomic status	Renter occupied housing units Mean housing unit value
Place dependency	Seasonal/recreational housing units
Water provider type	Proportion of housing units within municipal Proportion of housing units within private water provider service area Proportion of housing units with exempt wells

Indicator	**Information Required**	**Methodologies**
Exposure		
Dependence of population on groundwater	% of the population relying on groundwater for drinking and/or other purpose	Household interviews/ local statistics
Dependence of major economic sectors on groundwater	% of economic sectors in the study area relying on groundwater (e.g. agriculture, shrimp farming, bottling companies, tourism, etc.)	Desktop analysis, Interviews with land users
Ecological vulnerabilities	Major effects of groundwater depletion and pollution on natural ecosystems dependent on groundwater resources (e.g. oasis ecosystems, river basin flow systems etc.), such as change in flora and fauna, impacts on con	Literature review, Expert interviews
Well density	Location and density of groundwater wells per unit land indicate the pressure on aquifers.	Expert interviews, Desktop analysis, Household surveys
Hazard		
Groundwater quantity	Ratio of total groundwater abstraction to recharge	Secondary data; Expert interviews
Groundwater quality	Compared with country an / or WHO drinking water standards	
Sensitivity		
Groundwater vulnerability	Intrinsic vulnerability as a function of hydro-geological factors (e.g. net recharge, soil properties, topography, climate, unsaturated zone lithology and thickness, aquifer media, hydraulic conductivity and groundwater level below ground)	Secondary data; Literature review, Expert interviews
Population density	Historical data	National census data
Household structure	Number age and sex of family members and their relationships; characteristics of the household head	Household interviews/

Table 2-5: *Vulnerability archetypes, human well-being issues, responses and extreme climate events. (Modified from UNEP, 2007).*]

Archetype	**Extreme Climate Event**	**Human Well-Being Issues**	**Responses**
Contaminated Site (CS)	Impact on containment of hazardous materials by intense rainfall and floods; seepage during drought periods	Health hazards with impacts on communities living on or near CS or nations importing hazardous water for processing,	Improved laws and policies against special interests and increase participation of most vulnerable in decision making, relocation
Dry Lands	Drought	Decreasing supply of potable water, loss of productive land via desertirfication, environmental migration and ensuing conflict	Improvement of land tenure and management arrangements, provision of access to global markets.
Global commons	???	Decline or collapse of fisheries with partly gender specific poverty consequences; health consequences of air pollution and social and health consequences	Integrated regulations for fisheries, marine mammal exploitation and oil exploration; use of persistent organic compound policies for heavy metals
Securing Energy	Power outages due to heat waves, wind and ice storms, flooding of generator plants	Material well-being effects; marginalized affected by rising energy costs	Secure energy for the most vulnerable and encourage participation, foster decentralised and sustainable technology, invest in diversification of energy systems (renewables)
Small Island Developing States	Storm surge, wind storms, intense rainfall	Livelihoods of climate dependent natural resources most endangered; migration and conflict	Adapt by improving early warning; move to more climate independent economy; shift from controlling of to working with nature paradigm
Technology-centred approaches to water problems	Dam breaching by floods; drought and diversion of water to irrigation and non-domestic uses	Forced resettlement; uneven distribution of benefits from dam building; health hazards from water-borne vectors.	Stakeholder participation in decision making; dam alternatives such as small-scale solutions and green engineering
Urbanisation of the coastal fringe	Storm surge, intense rainfall and riverine/esturine flooding/landslides; heat and algal blooms	Lives and material assets endangered; poor sanitarty conditions and health impacts; unplanned coastal urbanisation in exposed areas	Implementation of Hyogo Framework of action on DRD; create opportunities for integrated coastal protection and livelihood options.

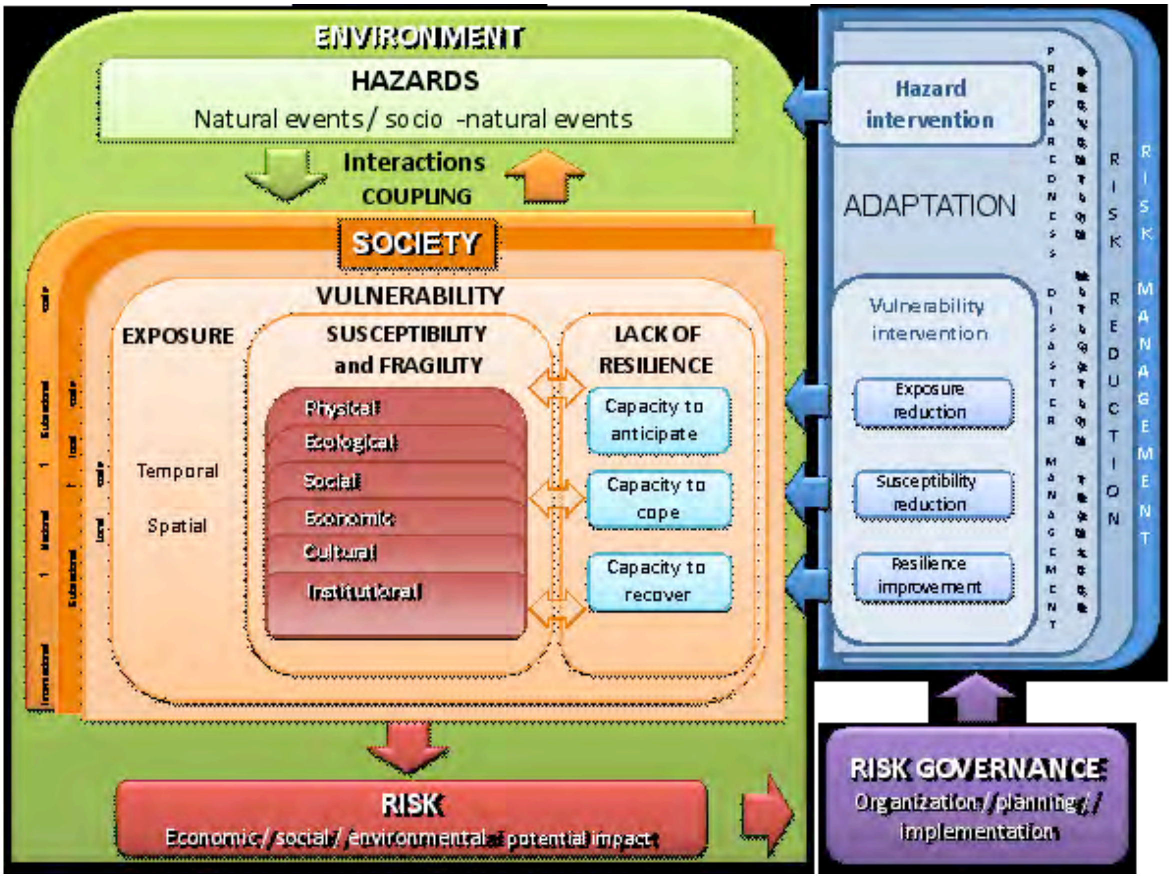

Figure 2-1: MOVE project framework on vulnerability and disaster risk assessment and management. Source: MOVE (2010).

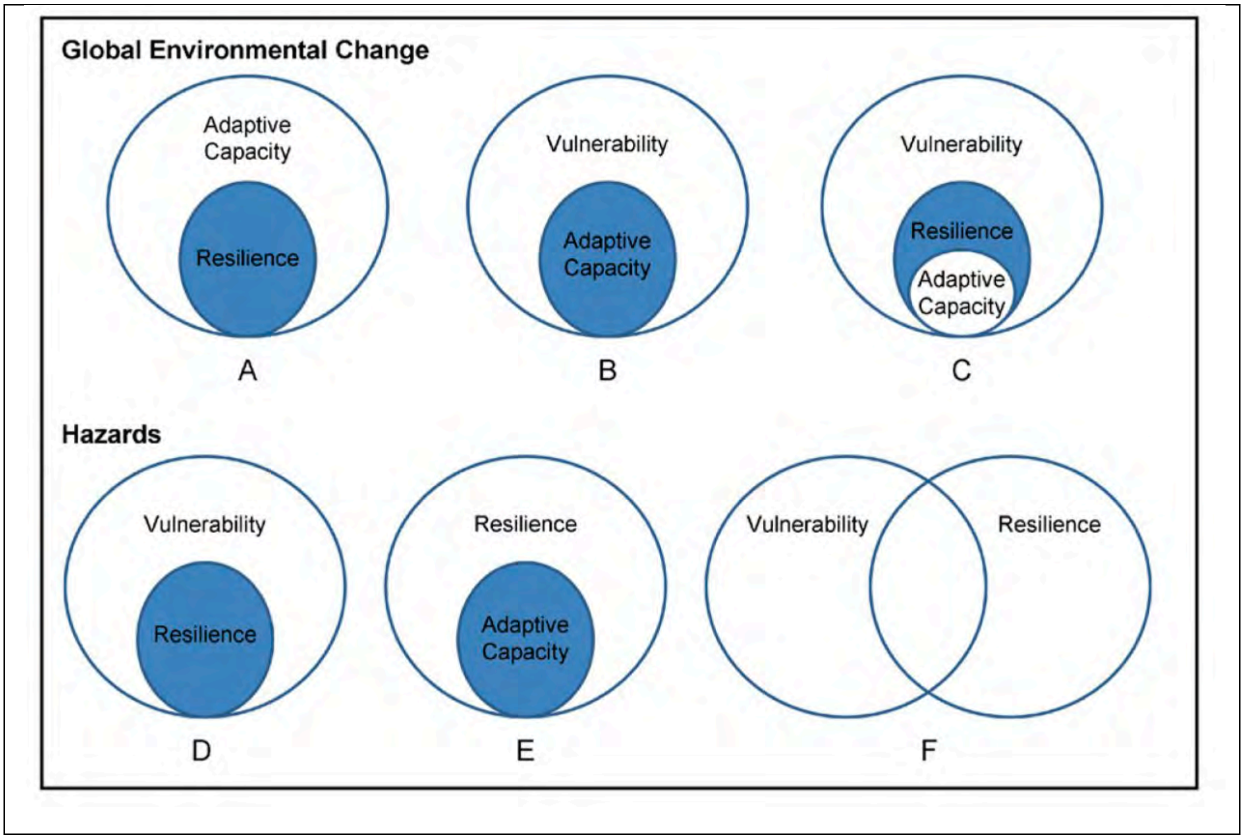

Figure 2-2: Conceptual framework relating adaptive capacity, resilience and vulnerability in the global environmental change and hazards communities of practice. Source: Cutter et al. (2008).

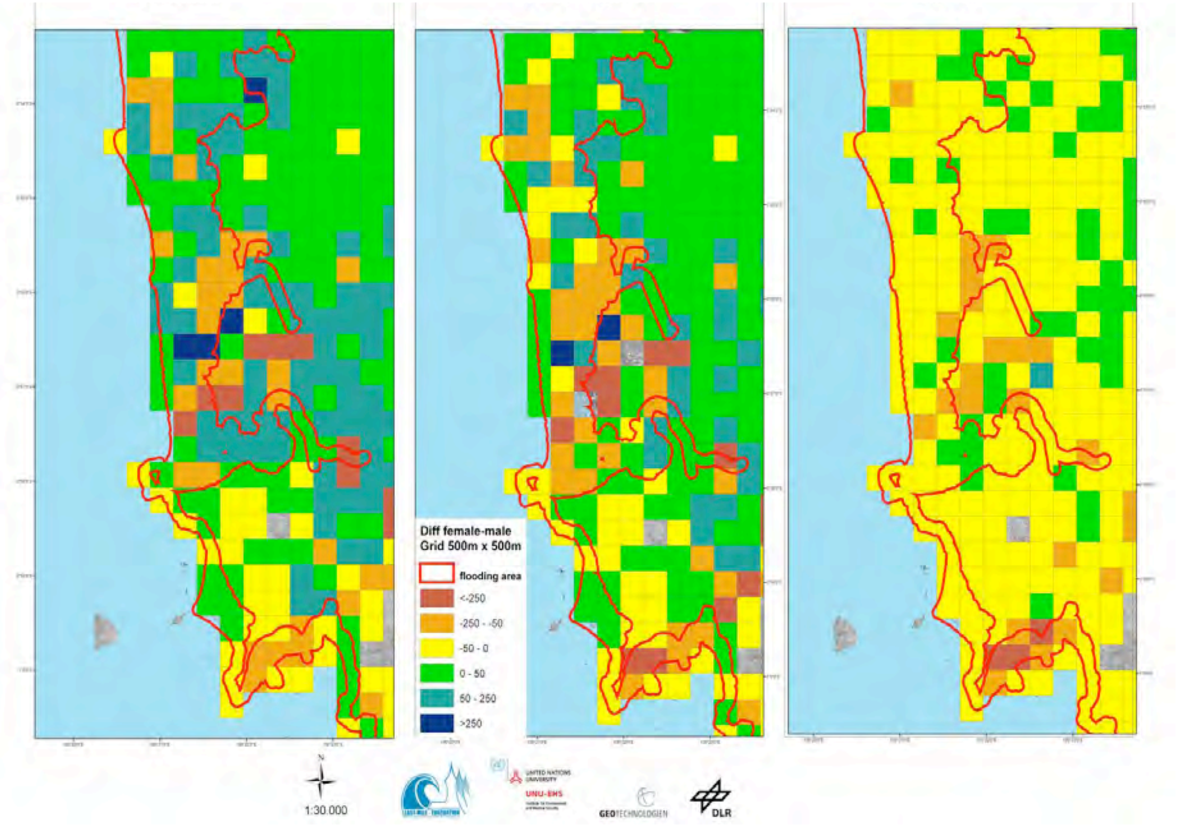

Figure 2-3: Difference between female-male population during morning, afternoon and night, for the coastal city of Padang, demonstrating differential exposure of women over time of day in the high risk zone close to the sea (Setiadi et al., 2010).

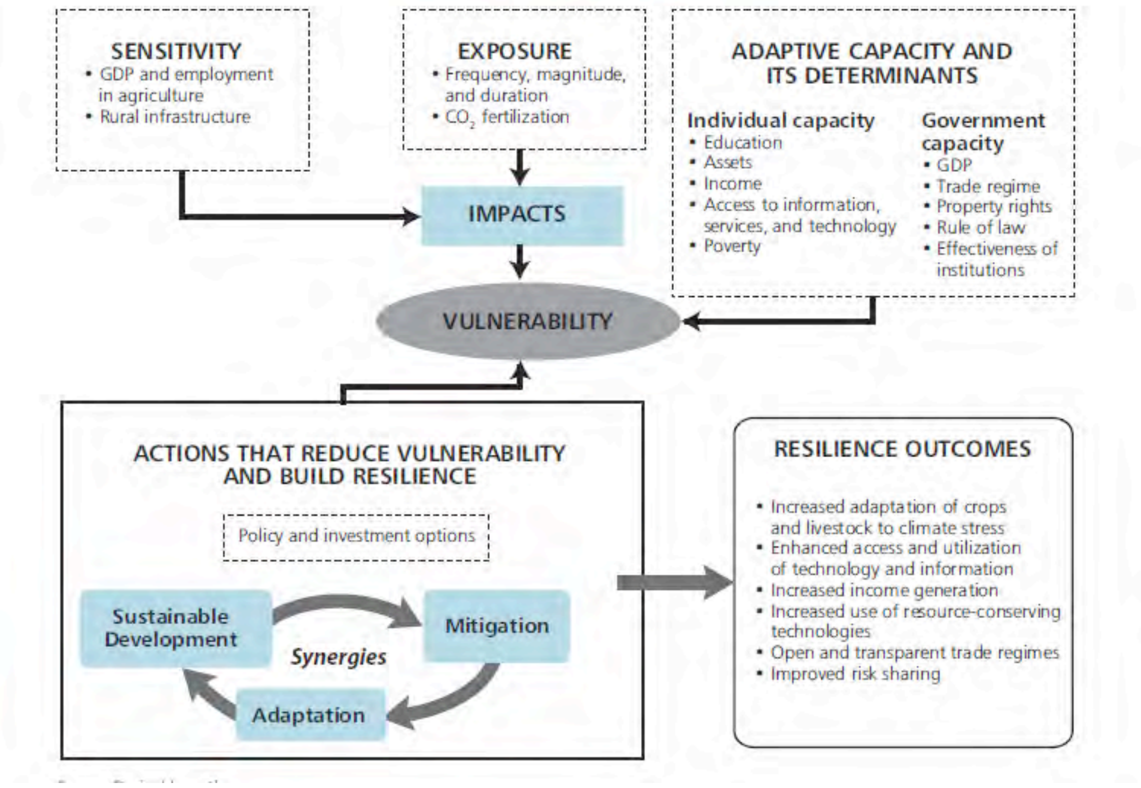

Figure 2-4: Relation between vulnerability and building resilience in the agriculture sector (ADB, 2009).

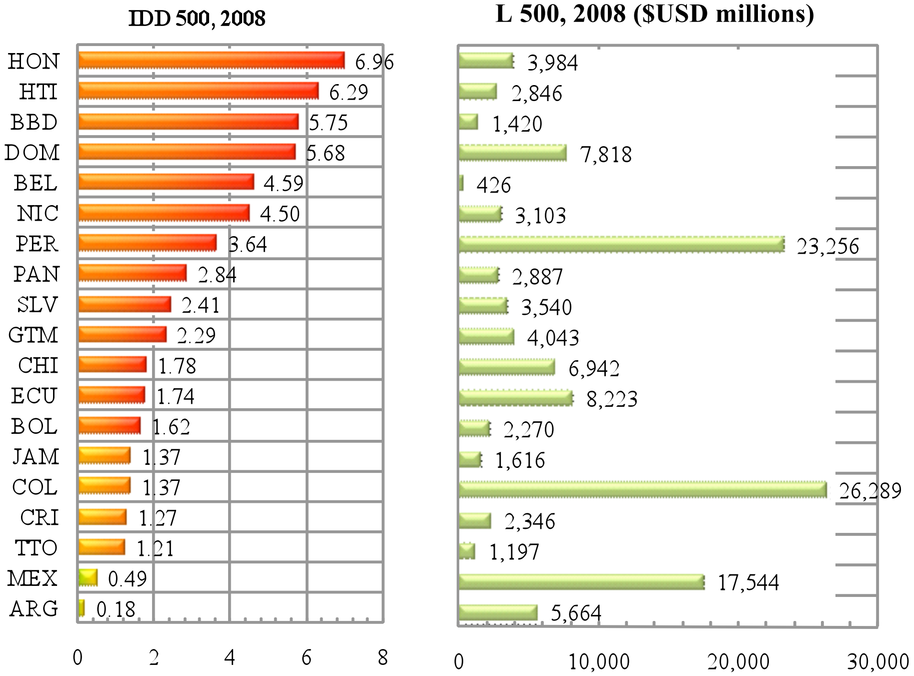

Figure 2-5: Disaster Deficit Index (DDI) and probable maximum loss in 500 years for 2008.

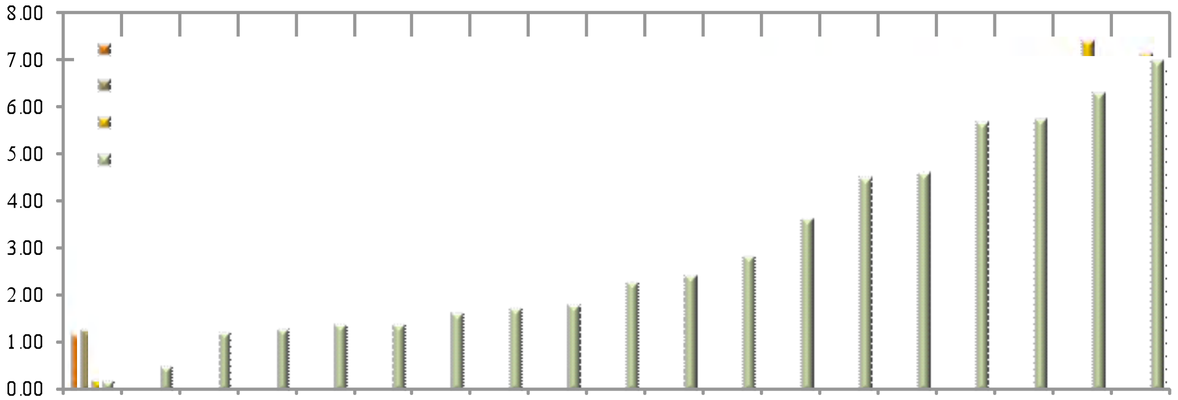

Figure 2-6: *Disaster Deficit Index (DDI) (500 years) for 19 countries of the Americas.*

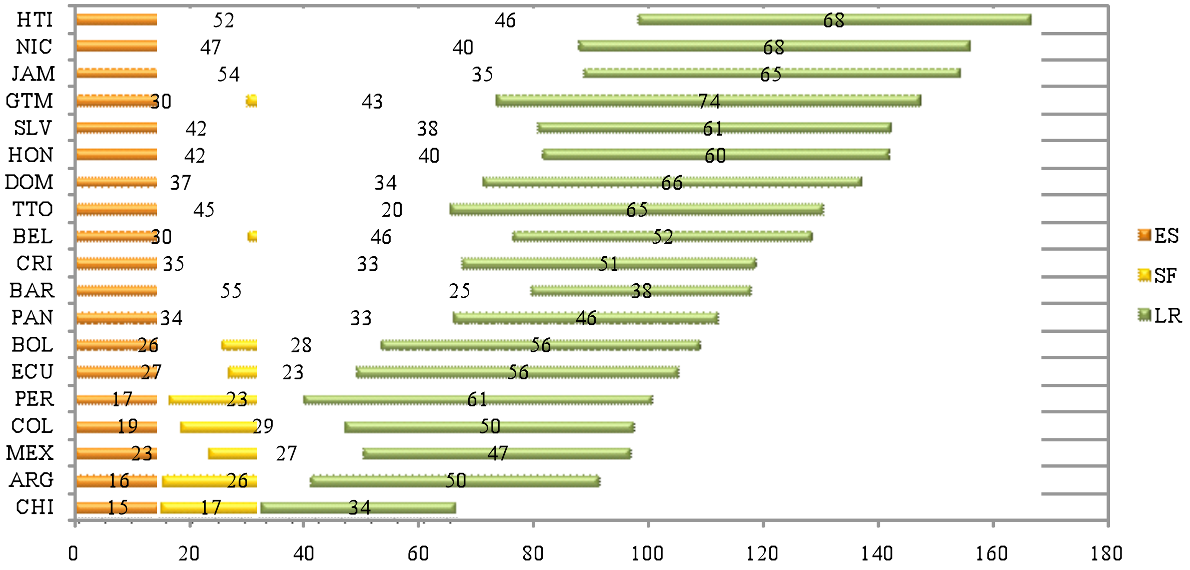

Figure 2-7: Aggregate Prevalent Vulnerability Index (PVI) for 2007.

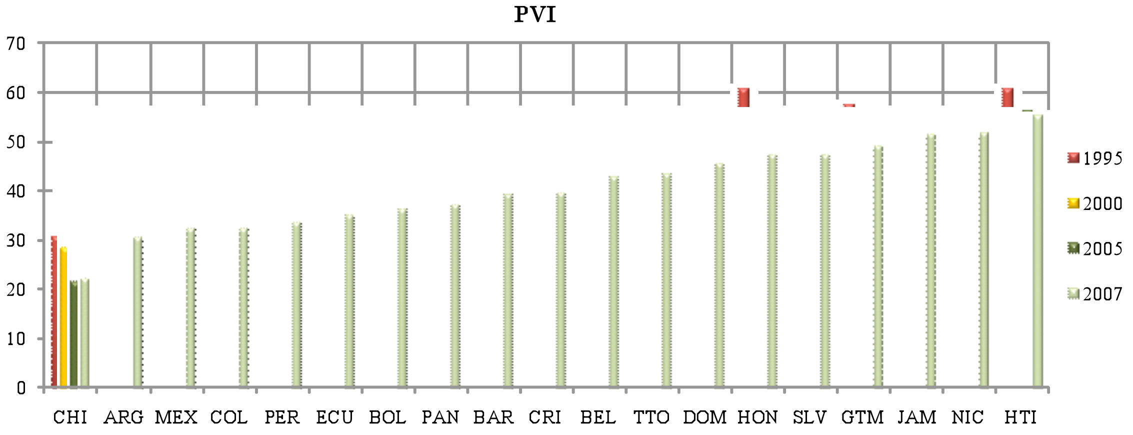

Figure 2-8: Prevalent Vulnerability Index (PVI) for 19 countries of the Americas.

Chapter 3: Changes in Climate Extremes and their Impacts on the Natural Physical Environment

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Executive Summary

The focus of this Chapter is on possible changes in the frequency and intensity of weather and climate extremes that may contribute to disasters. A changing climate may lead to changes in the frequency of occurrence of an extreme (rare event), or result in an unprecedented, previously unobserved, extreme. As well, a weather or climate event, although not drawn from the extreme tail of the distribution, still may be associated with disasters, possibly by leading to a crossing of a critical threshold in a social, ecological or physical system, or because it occurs simultaneously with another type of event combined with which it leads to extreme conditions (compound event). Some weather/climate events may increase the potential for disasters through their impacts on physical systems, such as floods and landslides after heavy rain. Phenomena such as El Niño are considered here because they can lead to climate extremes such as droughts and heavy rains in many regions simultaneously and this may be relevant to disaster management. As well, changes in phenomena such as El Niño or monsoons would also likely affect the frequency and intensity of extremes in several regions.

The events and phenomena examined in this Chapter are:

- Weather and climate elements (temperature; precipitation; winds)
- Weather and climate phenomena (monsoons; El Niño – Southern Oscillation and other modes of variability; tropical and extratropical cyclones)
- Impacts on the natural physical environment (droughts; floods; extreme sea level and coastal impacts; cryosphere and permafrost-related impacts; landslides; sand and dust storms)

For each of these events/phenomena/impacts, the evidence of whether or not they appear to be changing in frequency or intensity (and why) is summarised, as well as projections of future changes (and the confidence in these projections). The assessments herein are based on assessments in the IPCC AR4 modified, where appropriate, by post-AR4 research.

Research performed since the AR4 has reinforced the conclusion that for the period since 1950 it is *very likely* that there has been a decrease in the number of unusually cold days and nights, and an increase in the number of unusually warm days and nights on both a global and regional basis (where the respective extremes are defined with regard to the 1960-1990 base period). Furthermore, based on a limited number of regional analyses and implicit from the documented mean changes in daily temperatures, it is *likely* that warm spells, including heat waves, have increased since the middle of the 20th century. The few studies since the AR4 of annual maximum daily maximum and minimum temperatures suggest that human emission of greenhouse gases has *likely* had a detectable influence on extreme temperatures at the global and regional scales. Post-AR4 studies of temperature extremes have utilised larger model ensembles and generally reinforce the projections of changes in temperature extremes reached in AR4 as well as providing more regional detail (i.e., *virtually certain* warming trends in daily temperature extremes and *very likely* increases in heat waves over most land areas, the temperature extremes being defined with respect to the 1960-1990 base period). In some regions, the enhanced occurrence of hot extremes is projected to have particularly large impacts because they are associated with critical health thresholds.

Many studies conducted since the AR4 support its conclusion that increasing trends in precipitation extremes have *likely* occurred in many areas over the world. Overall, new studies since AR4 have substantially strengthened the AR4 assessment that it is *more likely than not* that anthropogenic influence has contributed to a global trend towards increases in the frequency of heavy precipitation events over the second half of the 20th century. The AR4 projected that it is *very likely* that the frequency of heavy precipitation (or proportion of total rainfall from heavy falls), will increase over most areas of the globe in the 21st century. In some regions, heavy daily precipitation events are projected to increase even if the annual total precipitation is projected to decrease. Post-AR4 analyses of climate model simulations generally confirm the AR4 assessment.

There is almost no literature on the attribution of the causes of any observed changes in strong winds, and thus no assessment can be provided at this time, as was the case in the AR4. Nonetheless, there have been several studies since the AR4 that have focussed on future changes in strong winds and the findings from these point to a decreased frequency of the strongest wind events in the tropics and increased frequency in the strongest wind events in the extratropics, although regional variations occur. However, the small number of studies of projected extreme winds, together with shortcomings in the simulation of these events, means that it is still difficult to credibly project changes in strong winds. Further complicating the projection of changes in tropical wind extremes is the projection of a *likely* increase in tropical cyclone winds.

The AR4 concluded that the current understanding of climate change in the monsoon regions remains one of considerable uncertainty with respect to circulation and precipitation. The AR4 projected that there "is a tendency for monsoonal circulations to result in increased precipitation mainly in the form of extremes due to enhanced moisture convergence, despite a tendency towards weakening of the monsoonal flows themselves. However, many aspects of tropical climatic responses remain uncertain." Post-AR4 work has not substantially changed these conclusions. At regional scales, there is little consensus in climate models regarding the sign of future change in the monsoons. Land use changes and aerosols from biomass burning have emerged as important forcings on the variability of monsoons, but are associated with large uncertainties.

Studies since the AR4 provide evidence of a tendency for recent El Niño episodes to be centred more in the central equatorial Pacific than in the east Pacific. In turn, this change in the location of the strongest sea surface temperature anomalies associated with El Niño may explain changes that have been noted in the remote (i.e, away from the equatorial Pacific) climate influences of the phenomenon. Apart from this, there is little evidence of trends in the temporal/seasonal nature of the El Niño–Southern Oscillation in recent decades. The possible role of increased greenhouse gases in affecting the behaviour of the El Niño – Southern Oscillation over the past 50-100 years is uncertain. Models project a wide variety of changes in ENSO variability and the frequency of El Niño episodes as a consequence of increased greenhouse gas concentrations. However, most models project a further increase in the relative frequency of central equatorial Pacific events.

Regarding other modes of climate variability, the AR4 noted that trends observed over recent decades in the North Atlantic Oscillation (NAO) and the Southern Annular Mode (SAM) were *likely* due in part to human activity. Recent studies also suggest that variability in the NAO is being affected by rising global temperatures and that projected warming may lead to a more positive NAO regime (although confidence in the ability of models to simulate the NAO is low). An increasing positive phase of the SAM in recent decades has been linked to stratospheric ozone depletion and to greenhouse gas increases. Models including both greenhouse gas and stratospheric ozone changes simulate a realistic trend in the SAM, although there is some concern that possible anthropogenic circulation changes are poorly characterized by trends in the annular modes. There is little consistency between model projections of these modes.

There have been no significant trends observed in the global annual number of tropical cyclones, including over the recent 40-year period of satellite observations. Regional trends in tropical cyclone frequency have been identified in the North Atlantic, but there is a lack of consensus regarding the fidelity of these trends. The uncertainties in the historical tropical cyclone records and the degree of tropical cyclone variability — comprising random processes and linkages to various natural climate modes such as El Niño — do not presently allow for the attribution of any observed changes in tropical cyclone activity to anthropogenic influences. It is *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged in future decades. An increase in mean tropical cyclone maximum wind speed is *likely*, although increases may not occur in all ocean basins. It is *more likely than not* that the increases in frequency of the most intense storms will vary substantially between ocean basins. It is *likely* that tropical cyclone-related rainfall rates will increase with greenhouse warming.

Research subsequent to the AR4 supports previous findings of a poleward shift in extratropical cyclones since the 1950s and an intensification of extratropical cyclones in high latitudes in the last 50 years. New evidence has strengthened the AR4 assessment that it is *likely* that anthropogenic forcing has contributed to the changes in extratropical storm tracks but a quantitative anthropogenic influence has not been detected formally, owing to large internal variability and problems due to changes in observing systems. It is *likely* that future anthropogenic climate change will influence regional cyclone activity. A reduction in mid-latitude storms averaged over each hemisphere is *likely* and it is *more likely than not* that high-latitude cyclone number and intensity will increase. There is little consistency among models regarding the detailed geographical pattern of projected cyclone activity changes.

The AR4 concluded from proxies based on precipitation data and estimates using the Palmer-drought severity index that it is *likely* that the intensity and duration of droughts have increased since the 1950s and that the area of drought-affected regions has increased since the 1970s. Anthropogenic influence on diagnosed drought trends was evaluated as *more likely than not* in the AR4. Research on regional drought since the AR4 further supports the above AR4 assessment. Lack of soil moisture observations partly prevents the analysis of trends in agricultural droughts in most regions, an issue also noted in the AR4. Post-AR4 studies have projected an increase in the global area affected by extreme drought over the 21st century being *likely*. However, the changes are dependent on the definition of the drought index, and on the region examined.

Research since the AR4 has not shown clear and widespread evidence of observed changes in floods at the global level except for the earlier spring flow in snow-dominated regions. After a period of frequent occurrence at the end of the Little Ice Age and a more stable period during the 20th century, glacial-lake outburst floods have increased in frequency in many regions. It is *more likely than not* that anthropogenic greenhouse gas emissions have affected floods because they have influenced components of the hydrological cycle, but the magnitude and even the sign of this anthropogenic influence is uncertain. The causes of regional changes in floods are complex. It is *likely* that anthropogenic influence has resulted in earlier spring flood peaks in snowmelt rivers. A few recent studies for Europe and one global study have projected changes in the frequency and/or magnitude of floods in the 21st century at a large scale. However, the sign of any projected trend varies regionally.

The AR4 reported that the rise in mean sea level and variations in regional climate led to a *likely* upward trend in extreme high water worldwide in the late 20th century. Subsequent to the AR4 a small number of additional studies of extreme sea levels have been undertaken, which support the AR4 conclusion, although some regional studies also note the relationship between extreme sea levels and modes of natural variability. It is *very likely* that mean sea level rise will contribute to upward trends in extreme sea levels in the future. The AR4 reported statistically significant positive trends in significant wave height in some parts of the globe for which data was available including most of the mid-latitudinal North Atlantic and North Pacific. Additional studies since the AR4 provide further evidence for positive trends in these and other locations. However, the small number of studies, and the different sources of wave data used in the studies, preclude a formal assessment at this time. Future changes to significant wave height are *likely* to reflect future changes in storminess and associated patterns of wind change. The AR4 concluded that hazards such as increased coastal inundation, erosion and ecosystem losses are adversely impacting coasts. New studies since the AR4 draw similar conclusions and also note the difficulty in apportioning the observed changes between natural climate variability, climate change and other anthropogenic causes.

Frequency of large landslides in cold regions and high mountains has *more likely than not* increased during the past two decades, and especially early into the 21st century. Earlier snow melt is *more likely than not* to result in earlier onset of high-mountain debris flows, and shallow landslides in lower mountain ranges are *more likely than not* to increase with the projected higher precipitation intensities. It is unclear if anthropogenic influence has contributed to any changes in temperate and tropical region landslides. New and potentially unstable lakes are *likely* to form during the 21st century following glacier retreat. Permafrost is *likely* thawing and has *likely* resulted in physical impacts in cold regions such as increased Arctic coastal erosion and development of thermokarst terrains and thaw lakes. The changes in permafrost and its associated physical impacts are *likely* due to anthropogenic influences because these changes are primarily caused by increase in air temperature and winter snow thickness. It is *likely* that permafrost will continue to thaw with an increase in its associated physical impacts. Due to projected sea ice retreat, and permafrost degradation, the frequency and magnitude of the rate of Arctic coastal erosion is *likely* to increase.

Over the past few decades, the frequency of dust events has increased in some regions such as the Sahel zone of Africa and decreased in some other regions such as northern China. There is high uncertainty in projected future changes in dust activity. Due to scarce evidence, assessments of the likelihood of past and projected changes in dust events, and the attribution of observed changes, cannot be provided at present.

In many cases changes in extremes closely follow changes in the average of a weather variable. However there are sufficient exceptions from this that one cannot assume that a change in an extreme will necessarily follow a change in the mean of the variable. This appears to be especially the case for short-duration heavy precipitation episodes, and temperature extremes at urban locations or in mid and high latitudes. For example, extreme precipitation is projected to increase even in some regions where total precipitation is projected to decrease.

This overall assessment highlights that our confidence in past and future changes including the direction and magnitude in extremes depends on the type of extreme, as well as on the region and season, linked with the level of understanding of the underlying processes and the reliability of their simulation in models. The different levels of confidence need to be taken into consideration in management strategies for disaster risk reduction involving climate and weather extremes.

3.1. Weather and Climate Events Related to Disasters

3.1.1. What Scientific Information is Needed to Inform Risk Management?

Extreme weather and climate events are important, albeit rare, aspects of the climate. The probability that a defined extreme event will occur at a given time and place is closely related to the statistical properties of climate at this location. This concept has found wide applications in engineering practice for many years: design values have been estimated from observed climate, and the likelihood for exceeding the design values has been assessed by assuming that climate within the expected life span of the engineering structure will remain the same as that from which the design values were derived. This presupposes, however, that climate is stationary (Milly et al., 2008). In a situation of transient climate changes, other approaches need to be developed to inform risk management.

When climate properties change at a location, the probability distribution functions (PDFs) for climate variables are modified, with attendant changes in the frequency and intensity of extreme events (as defined with respect to a past climatology). Different extremes and their related impacts may behave differently for a given change in mean climate, i.e., some may become more frequent, other less frequent. For example, in most locations, a globally warmer climate will probably make extreme high temperatures even warmer and thus more extreme, but it will also probably result in less extreme low temperatures. However, decreases in the occurrence or intensity of some extremes may not "compensate" for increases in other extremes, as a shift in the average climate means a change away from the range of climate to which natural and human systems have adapted, and in such circumstances it may thus be felt that the climate is becoming more extreme (FAQ 3.1). Moreover, changes in mean climate may also lead to the sudden occurrence of extremes that were not previously experienced at a given location, due to the crossing of critical thresholds, for instance in the case of heatwave-induced mortality, or the occurrence of droughts, floods, or storm surges (Box 3.1). Besides these changes in extremes associated with modifications of the mean climate, the statistical properties of the climate in some regions may also be modified in such a way that variability is changed, i.e., rare events become more (or less) distinct from the mean climate (Box 3.2). Finally, also contrasting extremes (both wet and dry extremes) or compound events may become more frequent in some regions (Section 3.1.4 and Box 3.4), and thus changes in given extremes or in the mean of some variables cannot be considered in isolation when assessing their resulting impacts on ecosystems and society.

Extreme weather and climate events occur on a wide range of space and time scales. A tornado may last for only a few minutes and cause damage only to a localized area. On the other hand, a drought may persist for years or even decades and may impact a region as large as a continent. In general, an extreme that occurs on a small time scale also tends to have a small space scale. The scale of extremes determines the data requirements for their analysis (e.g., hourly/daily versus monthly resolution, Section 3.2.1). It is also relevant to their understanding, as small-scale changes in a variable are often partially controlled by changes in other factors (topography, land-atmosphere exchanges) in addition to those induced by large-scale changes (large-scale circulation patterns, global temperature change). This consideration is further addressed in Section 3.2.2.

Preparedness for possible future changes in physical extremes requires several types of scientific information, including:

- Identification and definition of events that are relevant from a risk management perspective
- Observations and model experiments to analyse past and projected changes in identified extremes, and to identify the underlying mechanisms and causes
- Assessments of confidence in the likelihood of past and projected changes in extremes
- Prediction tools for early warning and forecasting of extremes, to allow adaptation to projected changes in identified extremes.

These various aspects are briefly addressed in the following subsections (3.1.1.1. to 3.1.1.4). The categories of weather and climate events that are considered in this chapter are discussed in Section 3.1.2, general characteristics of weather and climate events relevant to disasters are addressed in Section 3.1.3, and Section 3.1.4 and 3.1.5 briefly discuss issues associated with compound events, as well as the impacts of weather and climate extremes on the physical environment and associated feedbacks. Requirements and methods for investigating observed and projected changes, the underlying mechanisms and causes, and associated uncertainties are addressed in more detail in Sections 3.2.1 to 3.2.4. Finally, assessments on observed and projected changes in the considered weather and climate events are provided in Sections 3.3 to 3.5.

START BOX 3.1 HERE

Box 3.1: Extreme Impacts (of Non-Extreme Events) Versus Impacts of Extreme Events

As noted in Section 3.1.1.1, from a statistical perspective, extreme events are often defined as being equivalent to "rare" events, i.e., events from the extreme tails of the frequency distribution of a weather/climate variable (e.g., AR4 glossary definition). Many such extremes have a close association with disasters (e.g., heavy rainfalls with flood-related impacts, extreme temperatures with health impacts), though some rare events may not necessarily have extreme impacts in all climate regimes or regions.

In the context of a changing climate, an unprecedented extreme can arise when a trend in a weather/climate variable (e.g., temperature) contributes to a situation outside of the climatological frequency distribution for the variable (e.g., previously unobserved high temperature in this case). This may occur due to changes in mean, variability or shape (e.g., skewness) of the frequency distributions of the given weather/climate variables (Box 3.2). Note that because some of these changes may be slow (e.g., mean sea level rise), they might be considered as part of the climatological range within given time periods (i.e., 2nd half of 21st century), though extremes with respect to present-day climate. This aspect (abruptness of change) is also of strong relevance for adaptation, though we do not specifically address it in the present Chapter (e.g., temperature extremes are defined with respect to the 1960-1990 reference period in Tables 3.2 and 3.3. and Figures 3.1-3.4).

Events that may not be rare in a statistical sense (e.g., 80th percentile) may also be associated with extreme impacts, in particular if they are linked with the crossing of important thresholds: e.g., a medium deficit in precipitation in a region where mean evapotranspiration has significantly increased, moderately extreme ENSO events, or specific temperature thresholds for human health. Also the accumulation of several events which may each only be mildly extreme can lead to extreme impacts, as is the case for compound events or multiple clustered events (Section 3.1.4 and Box 3.4). Conversely, an extremely rare event may not necessarily lead to major impacts and disasters if it is not associated with some critical thresholds for the impacted systems (either by its nature or because of adaptation). Most global studies of changes in physical extremes do not consider how such extremes are related to actual impacts in the affected regions. While this aspect cannot be addressed in the present Chapter due to lack of corresponding literature, it should be noted that this gap could possibly be filled in the future if information on critical thresholds and their links to physical climate and weather events is more clearly inferred from impact studies (by conducting sensitivity experiments instead of driving impact models with single projections).

To illustrate how the resultant impacts may frame the definition of physical extremes and the identification of relevant changes in the context of global warming, Box 3.1, Figure 1 represents the relationship of the hypothetical frequency distribution of a weather/climate variable (top) with two impacts (bottom). In some cases, impacts may increase linearly with the intensity of the event. However, non-linear effects linked with discrete thresholds are common (e.g., Corti et al., 2009). The two hypothetical impact functions A and B in Box 3.1, Figure 1 (bottom) are assumed to be characterized by such critical thresholds. Note that these respective impact functions may be related either with physical (e.g., soil moisture content, slope instability) or social (health system, early warning systems, disaster risk management infrastructure) components, although we only consider the former of these two cases in the present Chapter given its scope. Threshold A lies within the present climate distribution and is not related to extreme conditions in a statistical sense, while threshold B lies outside the present climate distribution. From an impact perspective, both physical thresholds are relevant, even if only threshold B can be considered as a statistical extreme (AR4 definition) within the climate variable distribution.

INSERT BOX 3.1, FIGURE 1 HERE

Box 3.1, Figure 1: Link between climate/weather variable probability distribution function (PDF) and associated impacts (A and B), and implication for definition of "climate extremes" (see discussion in text). Note that the PDF of a climate variable is not necessarily Gaussian.

Box 3.1, Figure 2 illustrates possible changes in the frequency distribution of the weather/climate variable and the respective impact functions under climate change. The fact that a previously rare or extremely unlikely event occurs within the "new" climate is a function of the change in the PDF, i.e., in both mean and variability (examples C1 and C2), or even higher moments (e.g., skewness). However, the impact functions and related thresholds can also be modified (examples IA1 and IA2). This can be due to the adaptation of the society to the changed climate conditions (i.e., decreased impacts for the same threshold, and/or higher threshold, example IA1). Conversely, an increased vulnerability and susceptibility to damage for the same threshold may occur (example IA2), which may (or may not) be itself a consequence of climate change (e.g., modified land cover, compound events, increased overall vulnerability of society).

INSERT BOX 3.1, FIGURE 2 HERE

Box 3.1, Figure 2: Link between climate/weather variable PDF and associated impacts under climate change (see discussion in text). Note that the PDF of a climate variable is not necessarily Gaussian.

Hence, a comprehensive assessment of projected impacts of changes in climate extremes with enhanced greenhouse gas concentrations needs to consider how changes in atmospheric conditions (temperature, precipitation) translate to physical (e.g., droughts, floods, sea level rise), ecosystems (e.g., forest fires) and human systems (casualties, infrastructure damages) impacts. Links between climate events and physical impacts are addressed in the present chapter, while links to ecosystems and human systems impacts are addressed in Chapter 4. Note that these various impacts are related, since many impacts on human systems are themselves the results of impacts on physical systems or ecosystems.

An example of the complex links that can lead to physical impacts is illustrated in Figure 3.11 in Section 3.5.1. for the case of (meteorological, agricultural and hydrological) droughts. Similarly, Figure 3.12 in Section 3.5.5 illustrates the complex relationships between climate, weather phenomena and physical impacts in the coastal zone.

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FAQ 3.1: Is the Climate Becoming More Extreme?

While there is evidence that increases in greenhouse gases have likely caused changes in some types of extremes, there is no simple answer to the question of whether the climate, as a whole, has become more or less extreme than in the past. Both the terms "more extreme" and "less extreme" can be defined in different ways, resulting in different characterizations of observed changes in extremes. Additionally, from a physical climate science perspective it is difficult to devise a comprehensive metric that encompasses all aspects of extreme behaviour in the climate. Nevertheless, changes in integrative metrics of impacts, such as insurance payouts, could in principle provide a multi-sectoral indicator of whether the climate in a given region is becoming more extreme.

Widespread changes in some extremes (e.g., minimum temperatures) are being observed. Recent decades have also seen increasing weather and climate related insurance losses. As well, the media coverage of weather and climate disasters is becoming more global. With improving communication technology, news of a weather or climate disaster in one location can quickly spread to the whole world. As a result of all these factors, it is not surprising that the question of whether the global climate is becoming more extreme or more variable is often asked.

One possible approach for evaluating whether specific aspects of the climate are becoming more extreme would be to determine whether there have been changes in the habitual range of variation of certain climate variables. For example, if there was evidence that temperature variations in a given region had become significantly larger than in the past, then it would be reasonable to conclude that the temperature climate in that region had become more extreme. Temperature variations might therefore be considered as becoming more extreme if the difference between the highest and the lowest temperature observed in a year becomes increasingly larger. According to this approach, daily temperature over the globe may have become less extreme because there have generally been greater increases in annual minimum temperatures globally than in annual maximum temperatures. On the other hand, using such an approach, one might conclude that daily precipitation variations have become more extreme because observations suggest that the magnitude of the heaviest precipitation events has increased in many parts of the world.

Another approach, considering a somewhat different aspect of climate behaviour, would be to ask whether there have been significant changes in the frequency with which climate variables cross fixed thresholds that have been associated with human or other impacts (Box 3.1). For example, an increase in the mean temperature alone usually results in an increase in hot extremes such as "unprecedented" heat waves and a decrease in cold extremes. Such a shift in the temperature distribution would not increase the extremeness of day-to-day variations in temperature, but would be perceived as resulting in a more extreme warm temperature climate, and a less extreme cold temperature climate. Note however, that both of these changes may have serious impacts. For example, increases in heat stress related mortality in humans and other organisms has been observed when very high daytime maximum temperature thresholds are repeatedly crossed as in a heat wave, and the winter mortality of pests such as the pine bark beetle, decreases when critical winter low temperature thresholds are crossed less frequently in temperate climates.

Many other approaches for assessing changes in the extremeness of climate, involving different aspects of climate behaviour and either individual or multiple climate elements, could be considered. Such approaches could use the internationally accepted indictors that are designed to monitor changes in simple extreme events, such as the extremes of daily precipitation accumulations, but would also have to consider indicators of change in complex extreme events resulting from a sequence of individual events, or the simultaneous occurrence of different types of extremes (Box 3.4). As the discussion above suggests implicitly, it would be difficult to comprehensively describe the full suite of phenomena of concern, or to find a way to synthesize all such indicators into a single extremeness metric that could be used to comprehensively assess whether the climate as a whole has become more extreme from a physical perspective.

An inescapable fact of extremes is that their occurrence often has impacts that have economic consequences. It may therefore be possible to measure the integrated economic effects of the occurrence of different types of extremes into a common instrument such as insurance payoff to quantity if there has been an increase or decrease in that instrument. This instrument can be useful in risk management and disaster preparedness. But the development and use of such an instrument is always related to vulnerability and exposure and thus while it may, in principle, be possible to consider an instrument that is interpretable as a measure of climatic extremeness in a broad sense, it is difficult to disentangle changes in the instrument that reflect changes in vulnerability or exposure and that reflect changes in climate extremes. For example, coastal development can increase the exposure of populations to hurricanes; therefore, an increase in damage in coastal regions caused by hurricane landfalls may not be indicative of increased hurricane activity. Moreover, it may not always be possible to associate impacts such as the loss of human life or damage to an ecosystem due to climate extremes to a measurable instrument.

It appears that there is no simple answer to the question if climate, as a whole, has become more or less extreme than in the past. For example, depending upon how “more extreme” and “less extreme” are defined, observed changes in temperature and precipitation could be interpreted as indicating that the climate has become either more or less extreme. It is difficult to devise a metric with a clear physical interpretation that encompasses multiple aspects of extremes or variability of weather and climate in a region or in the world that quantifies changes in the extremeness of climate in some overall sense, since there are very many different sorts of climate extremes and the relationships between various types of extremes and their impacts on human systems and ecosystems can be very complex. Economic instruments, such as insurance payouts, could, in principle, provide a means for determining whether climate is becoming more extreme in a comprehensive step, but the instrument would have to be carefully designed so that it could effectively separate the effects of non-climatic factors, such as changes in vulnerability and exposure, from purely climatic factors.

END FAQ 3.1 HERE

3.1.1.1. Identification and Definition of Events that are Relevant from a Risk Management Perspective

The identification and definition of weather and climate events that are relevant from a risk management perspective is complex and depends on the stakeholders involved. For instance, it is essential to distinguish between events that are extremes in a statistical sense (but may not necessarily have extreme impacts), and events that, without being located in the tails (extremes) of the statistical distribution of the specific variable, can lead to major impacts and disasters (e.g., critical thresholds, compound events). This distinction is addressed in Chapter 1 and discussed further in Box 3.1.

This perspective implies that we consider in Chapter 3 a wider range of climate and weather events, phenomena and impacts than those strictly defined as “extreme events” in the IPCC AR4. Indeed, the AR4 Glossary (IPCC, 2007a) provides the following definition for extreme events: “An extreme weather event is an event that is rare at a particular place and time of year. Definitions of *rare* vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th *percentile* of the observed *probability density function*. By definition, the characteristics of what is called *extreme weather* may vary from place to place in an absolute sense. Single extreme events cannot be simply and directly attributed to *anthropogenic* climate change, as there is always a chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an *extreme climate event*, especially if it yields an average or total that is itself extreme (e.g., *drought* or heavy rainfall over a season).”

In this chapter, beside *extreme events* corresponding to the above definition, we also consider *phenomena* that can influence the occurrence and intensity of extreme events and disasters, and *physical impacts* (see Section 3.1.2). Climate phenomena such as El Niño and tropical cyclones induce extreme (low or high) precipitation, wind, sea surface temperatures (SSTs) and sea levels, and thus contribute to “extreme events”. However, they are *per se* “normal” features of climate variability. Because of their links to extreme events, we need to consider all of their occurrences, and not only “extreme” El Niño events and tropical cyclones. Similarly, because physical impacts such as droughts, floods and landslides may occur as the result of the (extreme) combination of several non-extreme events (Section 3.1.4), some aspects linked to changes in mean climate (e.g., mean temperature changes or mean precipitation changes) need to be considered as well.

Regarding the use of the term “rare” in the AR4 definition quoted above, it is important to note that the “rarity” of a weather or climate event is not a well-defined concept. First, different percentiles may apply to the definition of extremes depending on the considered variable. A one in ten event as referred to in the above AR4 definition (10th or 90th percentile) is in many cases not sufficiently rare to qualify as “extreme”, and 5th/95th or 1st/99th percentiles are more appropriate; but in some cases, even more frequent events (one in five) may qualify as extremes, for instance because they are associated with specific thresholds and/or the given events, phenomena or impacts do themselves only occur occasionally (e.g., El Niño). Furthermore, rarity can only be determined for a given time period and region. A rare event in the present climate (100-year flood or 99%-percentile temperature or sea level) may become much more common under the future climate conditions, and, strictly speaking, may thus not be an "extreme event" any more. Depending on the ability of society to adapt to such changes (which also depends on the pace at which they occur), these may or may not lead to enhanced impacts and disasters. We address issues related to the definition of "extreme events" and of weather and climate events related to disasters in more detail in Box 3.1 and Section 3.1.3.

START BOX 3.2 HERE

Box 3.2: Do Changes in Extremes Scale with Changes in Mean Climate?

Changes in extremes can be caused by changes in the mean, or variability, or both. Thus a change in the frequency of occurrence of hot days (i.e, days above a certain threshold) can arise from a change in the mean daily maximum temperature, or from a change in the variability or shape of the frequency distribution of daily maximum temperatures. Most climate change research, whether focussed on past, current or projected changes, has concentrated on documenting changes in mean quantities such as average temperatures, or total precipitation. If changes in the frequency of occurrence of hot days were mainly caused by changes in the mean daily maximum temperature, and changes in the shape and variability of the distribution of daily maximum temperatures were of secondary importance, then we may say that changes in the frequency of hot days "scaled" with changes in mean maximum temperature. If this was generally the case then it might be reasonable to use projected changes in mean temperature to estimate how changes in extreme temperatures might change in the future. If, however, changes in the shape and variability of the frequency distribution of daily maximum temperature were important, such extrapolation from changes in the mean maximum temperature to changes in the frequency of occurrence of hot days would be less credible. Is there evidence that the effect of changes in the mean temperature on the frequency of occurrence of an extreme event such as a hot day is sufficiently strong that we can ignore possible changes in the variability and shape of the frequency distribution?

Evidence regarding how strongly changes in extreme temperatures "scale" with changes in the mean temperature comes from empirical and modelling studies. Griffiths et al., (2005) examined trends (1961 – 2003) in daily maximum and minimum temperatures across the Asia – Pacific region. Significant decreases were observed in both maximum and minimum temperature standard deviation in China, Korea and some stations in Japan (probably reflecting urbanization effects), but also for some Thailand and coastal Australian sites. The South Pacific convergence zone (SPCZ) region between Fiji and the Solomon Islands showed a significant increase in maximum temperature variability. They concluded that for non-urban stations, the dominant distribution change for both maximum and minimum temperature involved a change in the mean, impacting on one or both extremes, with no change in standard deviation. This occurred from French Polynesia to Papua New Guinea (except for maximum temperature changes near the SPCZ), in Malaysia, the Philippines, and several outlying Japanese islands. For urbanized stations changes in *both* the mean and variance, impacting on one or both extremes, were found. This result was particularly evident for minimum temperature. These results suggest that changes in mean temperature may be used to predict changes in extreme temperatures, at least for non-urban tropical and maritime locations. But at urbanized or higher latitude locations, changes in variance should be considered as well. This is also illustrated by Figure 3.5 and analyses for the European continent (e.g., Klein Tank and Können, 2003; Brunet et al., 2006; Della-Marta et al., 2007b, see also Section 3.3.1.1)

An assessment of available studies of short-duration heavy precipitation in northern America (CCSP, 2008) found that in some regions there was an *increase* in heavy and/or very heavy precipitation even if there was no change or even a decrease in total (seasonal or annual) precipitation. So the assumption that extreme short-duration precipitation "scales" with changes in the total precipitation does not seem to be justified.

Models can also be used to examine the strength of the relationships between changes in mean or total quantities, and changes in extremes. Christensen and Christensen (2003) used a high-resolution climate model to examine the influence of greenhouse-gas-induced global warming upon heavy or extended precipitation episodes in Europe. Their results indicated that CO_2-induced warming might lead to a shift towards heavier intensive summertime precipitation, despite a projected mean decrease in summer precipitation, and suggested that this might be explained by the fact that the atmosphere will contain more water in a warmer climate (according to the Clausius–Clapeyron equation). Frei et al., (2006) analysed precipitation extremes simulated and projected by six European regional climate models (RCMs) and found that projected extremes increased more or decreased less than would be expected from the scaling of present day extremes. Also in Central Europe, climate-change projections suggest a stronger increase of temperature extremes compared to mean temperature (Fischer and Schär, 2010), in particular associated with soil moisture-temperature feedbacks (Seneviratne et al., 2006a).

Kharin et al., (2007) examined temperature and precipitation extremes and their potential future changes from an ensemble of global coupled climate models used in AR4. They found that changes in warm extremes were generally associated with changes in the mean summertime temperature. Cold extremes warmed faster than warm extremes by about 30%–40%, globally averaged, although this excessive warming was generally confined to regions where snow and sea ice retreat with global warming. With the exception of northern polar latitudes, relative changes in the intensity of precipitation extremes generally exceed relative changes in annual mean precipitation, particularly in tropical and subtropical regions.

The results of both empirical and model studies thus indicate that although in some situations extremes do scale closely with the mean, there are sufficient exceptions from this that changes in the variability and shape of probability distributions of weather variables need to be considered as well as changes in means, if we are to reach credible conclusions regarding possible future changes in extremes. This appears to be especially the case for short-duration precipitation, and temperatures at urban locations or in mid- and high-latitudes.

END BOX 3.2 HERE

3.1.1.2. Observations and Model Experiments to Analyse Past and Projected Changes in Identified Extremes, and the Underlying Mechanisms and Causes

The availability of observational data to analyse changes in identified events and to investigate the mechanisms of such changes is of central relevance for risk management. While observational data for variables such as temperature and precipitation are generally available in many parts of the world (despite a number of issues with these data), some other variables are almost unmonitored (soil moisture), or not monitored with sufficient temporal or spatial resolution to assess certain extremes (wind). Furthermore, changes in exposure and other problems can limit the availability of data to assess changes in monitored climate variables (which require long, homogenous series of observations). There has been progress regarding data issues in the past 15 years, partly in response to previous IPCC assessments that strongly highlighted these problems. These various aspects and their relevance to the analysis of trends in extremes are addressed in Section 3.2.1.

In order to produce credible projections of changes in identified climate events, phenomena or impacts, the relevant processes leading to these need to be reliably represented in global climate models (GCMs). This may not be feasible for all types of climate events, especially to the level of detail that is required for inferring associated impacts (Section 3.2.3). Indeed, some variables are not well or not at all simulated in current GCMs, and few observations are available to constrain or improve their representation. In some cases, dynamical or statistical downscaling can be used to compensate for these issues (for instance, by improving the representation of topography and land surface heterogeneity and their influence on extreme events), although downscaling has other inherent limitations (Section 3.2.3). Because of these issues, projections in some extremes are difficult or even impossible to provide, although projections in some other extremes have a high level of confidence (see next subsection).

3.1.1.3. Assessments of Confidence in Estimates Regarding Likelihood of Changes in the Extremes

Key information necessary for risk management includes the confidence in estimates regarding the likelihood of changes in identified relevant (extreme) events and the credibility of climate models in capturing and projecting the underlying processes. Indeed, risk management requires these in order to assess the uncertainty in the given projections, the risk of occurrence of relevant events, and the cost of preventive measures.

Given the relevance of this aspect for risk management and adaptation, it is important to note that changes in some extremes are easier to assess than in others either due to the complexity of the underlying processes or to the amount of evidence available for their understanding. This results in differing levels of uncertainty in climate simulations and projections for different extremes (Box 3.3). For instance, recent studies have highlighted that observed trends tend to be better reproduced by climate models in the case of temperature extremes than for precipitation extremes. Similarly, projections of changes in temperature extremes tend to be more consistent between climate models than is the case for (wet and dry) precipitation extremes. Other, more complex extremes are even more difficult to simulate and project (e.g., agricultural/soil moisture drought, wind extremes, tropical and extra-tropical cyclones). These issues are addressed in more detail in the individual sections on the specific extremes, phenomena and physical impacts considered in this chapter (Sections 3.3. to 3.5), as well as in Box 3.3. Overall, we can infer that **our confidence in past and future changes in extremes depends on the type of extreme, as well as on the region and season, linked with the level of understanding and reliability of simulation of the underlying processes** (Box 3.3).

In this chapter, all assessments regarding past or projected changes in extremes are expressed using likelihood statements, as described in the AR4 Working Group I Technical Summary (Solomon et al., 2007). As pointed by Risbey and Kandlikar (2007), likelihood statements implicitly include confidence assessments of the tools and data basis (models, data, proxies) used to assess or project changes in a specific element, and the associated level of understanding. Thus, in the case of changes in extremes for which confidence in the "tools" or "data basis" is low, no likelihood assessment would be provided, even if the available climate projections display a high congruence. Examples of such cases for model projections are when models display a poor performance in simulating the specific extreme in the present climate, or when insufficient literature on model performance is available for the specific extreme, e.g., due to lack of observations. Similarly for observed changes, evidence may be based on scattered data (or publications) that are not sufficient to provide a robust assessment for a large region, or the observations may be of poor quality or only of indirect nature (proxies). In the case of changes in extremes for which confidence in the models and data is rated as "medium" (that is we have some confidence in the tools and evidence available to us, but there remain substantial doubts about the quality of these tools), likelihood assessments could be provided but would be weakened to take into account the level of confidence. In such cases the assessment would be that a specific change is "more likely than not" if enough evidence is available to at least indicate the direction of the change., however no stronger assessment would be provided. Note that this means that assessments such as "likely", "unlikely", "very likely", "very unlikely", "virtually certain" or "exceptionally unlikely" are only provided for changes in which confidence in the tools and data is high. In cases with low confidence regarding past or projected changes in some extremes, no likelihood statement is provided, but in such cases we specify whether the low confidence is due to lack of literature, lack of evidence (data, observations), or lack of understanding (Table 3.1).

START BOX 3.3 HERE

Box 3.3. How does the Credibility of Climate Change Projections of Extremes Differ Geographically and Between Variables?

Comparisons of observed and simulated climate demonstrated good agreement for many climate variables, especially at large horizontal scales (e.g., Räisänen*,* 2007). For instance, Box 3.3, Figure 1 and Box 3.3, Figure 2, which are reproduced from Figure 9.12 of the IPCC AR4 (Hegerl et al.*,* 2007) compare the ability of 14 climate models to simulate the decadal variations of temperature through the 20th century. When the models included both natural and anthropogenic forcings, they consistently reproduced the decadal variations in global mean temperature (see panel at bottom left-hand corner of Box 3.3, Figure 1). Without the anthropogenic influences the models consistently failed to reproduce the decadal temperature variations. However, when the same models' abilities to simulate the temperature variations on smaller domains are assessed, although the mean temperature produced by the ensemble generally tracked the observed temperature changes, the consistency between the models was poorer than was the case for the global mean. We can conclude that the smaller the spatial domain for which simulations or projections are being prepared, the less confidence we should have in these projections.

This increased uncertainty at smaller scales results from larger internal variability at smaller scales or "noise" (i.e., natural variability unrelated to external forcings) and increased model uncertainty (i.e., less consistency between models) at these scales (Hawkins and Sutton*,* 2009). The latter factor is largely due to the role of unresolved processes (representations of clouds, convection, land-surface processes, see also Section 3.2.3). Hawkins and Sutton (2009) also point out regional variations in these aspects: In the tropics the signal expected from anthropogenic factors is large relative to the model uncertainty and the natural variability, compared with higher latitudes. Box 3.3, Figure 1 and Box 3.3, Figure 2 also indicate that the models are more consistent in reproducing decadal temperature variations in the tropics than at higher latitudes, even though the magnitudes of the temperature trends are larger at higher latitudes.

INSERT BOX 3.3, FIGURE 1 HERE

Box 3.3, Figure 1: Comparison for the Americas of multi-model data set of model simulations containing all forcings (red shaded regions) and containing natural forcings only (blue shaded regions) with observed decadal mean temperature changes (°C) from 1906 to 2005 from the Hadley Centre/Climatic Research Unit gridded surface temperature data set (HadCRUT3, Brohan et al., 2006). The panel labelled GLO shows comparison for global mean; LAN, global land; and OCE, global ocean data. Remaining panels display results for 22 sub-continental scale regions. Shaded bands represent the middle 90% range estimated from the multi-model ensemble. Note that the model simulations have not been scaled in any way. The same simulations are used as in Figure 9.5 of AR4 (58 simulations using all forcings from 14 models, and 19 simulations using natural forcings only from 5 models) (Hegerl et al., 2007). Each simulation was sampled so that coverage corresponds to that of the observations, and was centred relative to the 1901 to 1950 mean obtained by that simulation in the region of interest. Observations in each region were centred relative to the same period. The observations in each region are generally consistent with model simulations that include anthropogenic and natural forcings, whereas in many regions the observations are inconsistent with model simulations that include natural forcings only. Lines are dashed where spatial coverage is less than 50%. From Hegerl et al., (2007).

INSERT BOX 3.3, FIGURE 2 HERE

Box 3.3, Figure 2: Same as Box 3.3, Figure 1 for Europe, Africa, Asia and Oceania. From Hegerl et al., (2007).

Uncertainty in projections of extremes also depend on the considered variables, phenomena or impacts. There is more model uncertainty for variables other than temperature, especially precipitation (Räisänen*,* 2007; Hawkins and Sutton*,* 2010, see also Section 3.2.3). And the situation is more difficult again for extremes. Thus climate models simulate changes in extreme temperatures quite well, but the frequency, distribution and intensity of heavy precipitation is less well simulated (Randall et al.*,* 2007) as are changes in heavy precipitation (e.g., Alexander and Arblaster*,* 2009). Also projections of changes in temperature extremes tend to be more consistent across climate models than for (wet and dry) precipitation extremes (Tebaldi et al.*,* 2006) and significant inconsistencies are also found for projections of agricultural (soil moisture) droughts (Wang*,* 2005). For some other extremes, such as tropical cyclones, differences in the regional-scale climate change projections between models can lead to marked differences in projected tropical cyclone activity associated with anthropogenic climate change (Knutson et al.*,* 2010), and thus decrease confidence in projections of changes in that extreme.

In summary, confidence in climate change projections is greatest for temperature, especially on global scales, and decreases when other variables are considered, and as we focus on smaller spatial domains. Confidence in projections for extremes is lower than for projections of long-term averages.

END BOX 3.3 HERE

3.1.1.4. Prediction Tools for Early Warning and Forecasting of Extremes

In the context of global warming, climate models can be used not only for long-term climate change projections, but also for short-term and, in particular, subseasonal and seasonal-to-interannual predictions (with some differences in the level of complexity of the represented physical processes). In this respect, they can also be viewed as tools potentially helping adaptation to climate change, despite limitations for some climate extremes (Sections 3.1.1.3 and 3.1.1.4). There have been significant advances in this research field in recent years and new developments are currently taking place (Case study9.x, Chapter 9). These applications, which provide a direct testing of model algorithms, might also help improve the quality of long-term projections for currently less well simulated climate extremes.

3.1.2. Categories of Weather and Climate Events to be Discussed in this Chapter

In this Chapter, we focus on changes in weather and climate relevant to extreme events and disasters, grouped into the following categories (Table 3.1):

- Weather and climate elements (temperature, precipitation, wind)
- Phenomena influencing the occurrence of weather and climate extremes (monsoons, El Niño and other modes of variability, tropical and extratropical cyclones)
- Impacts on the natural physical environment (droughts, floods, extreme sea level, waves, and coastal impacts, as well as other physical impacts, including cryosphere and permafrost-related impacts, landslides, and sand and dust storms)

The possible relevance of these elements, phenomena, and impacts to disaster risk management is discussed in Sections 3.3 to 3.5, along with observed and projected changes and the apparent causes and uncertainties. Table 3.1 summarises our overall (global) assessments of observed and projected changes, and of the attribution of the observed changes, for each category or phenomenon. Note that impacts on ecosystems (e.g., bushfires) and human systems (e.g., urban flooding) are addressed in Chapter 4. Tables 3.2 and 3.3 (and Figures 3.1 to 3.4) provide more regional detail of observed and projected changes in temperature and precipitation extremes, for which there is more detailed information available than for some of the other events and phenomena listed in Table 3.1.

INSERT TABLE 3.1 HERE

Table 3.1: Overview of considered extremes and summary of observed and projected changes on global scale. Regional details on observed and projected changes in temperature and precipitation extremes are provided in Tables 3.2 and 3.3.

It is noteworthy that the distinction between the three categories outlined above and in Table 3.1 is somewhat arbitrary, and many categories are related. In the case of the third category, "impacts on the natural physical environment", a specific distinction between these events and those considered under "weather and climate elements" is that they are not induced by changes in only one of the considered weather and climate elements, but are generally the results of specific conditions in several elements, as well as of some surface properties or states. For instance, both floods and droughts are related to precipitation extremes, but are also impacted by other meteorological and surface conditions (and are thus often better viewed as compound events, see, e.g., Section 3.1.4 and Box 3.4). Indeed, floods will more likely occur over saturated soils (Section 3.5.2), even in the case of moderate precipitation events, and droughts can be linked to precipitation deficits but may in many cases also be impacted by enhanced temperature and radiation and associated evapotranspiration excess as well as by pre-event soil moisture conditions (Section 3.5.1). Similar considerations apply to the other types of extremes included in this category.

Another arbitrary choice made here is the separate category for phenomena that are related to weather and climate extremes, such as monsoons, El Niño, and other modes of variability. These phenomena affect the large-scale environment that, in turn, influences extremes. For instance, El Niño episodes typically see droughts in some regions with, simultaneously, heavy rains and floods occurring elsewhere. Similarly, impacts of monsoons in terms of weather and climate extremes are generally related to either drought or flood conditions induced by the monsoon conditions. It could, of course, be feasible simply to examine such changes under the respective headings of "droughts" and or "heavy precipitations", or "floods". However, a change in the frequency or nature of El Niño – Southern Oscillation episodes would affect extremes in many locations simultaneously (also linked with modifications of the relationships between these episodes and precipitation in specific regions). Similarly, changes in monsoon patterns would affect large regions and often several countries. This is especially important from an international disaster perspective because coping with disasters in several regions simultaneously may be challenging (see also Box 3.4).

3.1.3. Characteristics of Weather and Climate Events Relevant to Disasters (Duration, Timing, Magnitude)

Several physical characteristics of climate and weather events are relevant to disasters. One important characteristic is the rarity of the given event, i.e., whether it is located in one of the extreme tails of the distribution of the weather/climate variable ("extreme event" following the definition provided in the IPCC AR4 glossary, see Section 3.1.1.1). Other relevant aspects include the event's duration, intensity, spatial area affected, timing, frequency, onset date, continuity (i.e., whether there are "breaks" within a spell), and pre-conditioning (e.g., rapid transition from a slowly developing meteorological drought into an agricultural drought). Those aspects most relevant for resulting impacts are determined by potential critical thresholds within the affected physical systems, ecosystems or human systems (Box 3.1).

The very nature of extremes, their differing spatial and temporal scales, and their dependency on the climate state and context (i.e., season and region, such as summer versus winter droughts in extratropical regions), means that it is not practical nor useful to define extremes precisely (see also Sections 3.1.1.1 and Box 3.1). In the climate literature, the term "extreme events" has been used broadly to describe a range of phenomena. Different definitions and thresholds have been used in different analyses.

One way to examine changes in short duration extreme events (or weather extremes) is to analyze descriptive extremes "indices" based on daily data. These indices may summarize complex events, such as the frequency of tropical cyclones of a given intensity within an ocean basin, but more often they involve basic weather elements such as temperature or precipitation. Such indices often involve the calculation of the number of days in a year exceeding specific thresholds defined relative to the climate such as 90th percentile or as a fixed value. Examples of such "day-count" indices (Alexander et al., 2006) are the number of days with minimum temperature below the long-term 10th percentile in the 1961–1990 base period (relative thresholds), or the number of days with rainfall amount higher than 25mm (absolute thresholds). These extreme events are of moderately extreme nature and typically occur a few times every year. Indices that are based on the frequency of exceedance of absolute thresholds (e.g., a daily rainfall exceeding 25mm or the number of frost days) may not reflect extremes in all locations. Day-count indices based on relative thresholds such as percentiles partially allow for spatial comparisons, because they sample the same part of the PDFs of the given variables at each location. Averaging such indices across large regions may enhance signal to noise ratios and thus improve the chances of detecting the responses of extremes to external forcing. Nonetheless, the comparability can be hindered by the fact that the PDFs may actually look very different in the tail beyond the indicated percentile values. Depending on their definition (for instance whether they consider seasonal changes), it may also be difficult to link the changes in these indices with underlying physical processes or changes in impacts. For example, a decrease in the annual number of days with minimum temperature below the long-term 10th percentile may be due to an increase in winter temperature and/or an increase in summer temperature, and thus may not be induced by the same processes nor correspond well with changes in low-temperature related impacts in all regions. For this reason, mechanistic and impact studies generally need to be performed on the regional scale and have to consider the timing of extremes. In the case of impact studies, regional vulnerability also needs to be taken into account: indeed, similar percentiles may not be associated with the same impacts in different regions (Box 3.1).

Such "extremes indices" can also be expanded to include events that are not necessarily of short duration (e.g., longest drought period within a 10-year period) or even quantities that are not extreme events per se (e.g., growing season length) but can be related to impacts and disasters induced by climate and weather events. They may also be based in some cases on monthly values rather than daily data. It is important to note that the processes that produce short duration extreme weather events and long duration extreme climate events (e.g., multi-year drought) can be very different. As a result, daily weather occurring during an extreme climate event may not always be extreme. For example, if a summer is extremely wet (i.e, the **seasonal rainfall total** is well above average), this does not necessarily mean that extreme **daily** precipitation amounts will be observed during that summer, and in fact, there can still be days without any precipitation. This is why sets of extreme indices need to be optimally chosen so as to consider the range of characteristic time scales of impacts and disasters induced both by weather and climate events.

Several lists of extreme indices have been established within international projects and initiatives (sometimes including more than 100 indices). The usefulness of such lists of indices is that they allow comparability across studies, as well as between observational and modelling studies. Moreover, in the case of observations, derived indices may be easier to get access to than raw data, which are generally not freely distributed by meteorological services. Examples of studies based on the analysis of such extreme indices are provided in e.g., Jones et al., (1999), Haylock and Nicholls (2000), Frich et al., (2002), Klein Tank et al., (2002), Schmidli and Frei (2005), Alexander et al., (2006), Tebaldi et al., (2006), Perkins et al., (2009).

An alternative approach to the use of extreme indices is statistical Extreme Value Theory (EVT), which is generally used to describe the frequency and intensity of rare events that typically occur less than once per year or period of interest. One approach, called the block maximum approach, predicts that the most extreme value in a block (of time) will tend to have the Generalized Extreme Value distribution (GEV; e.g., Coles, 2001) as the block lengthens. Applications in climatology typically consider blocks to be of length one season, one year or in some cases, multiple years. Empirical evidence suggests that for weather elements such as temperature, precipitation, and wind speed, the GEV distribution does indeed provide a good description of the behaviour of block maxima for blocks of a season or longer. An alternative formulation of the problem, in which exceedances above a very high threshold are studied, leads to the Generalized Pareto distribution (Coles, 2001). While used less frequently, this approach is also generally found to provide satisfactory descriptions of the frequency and intensity of rare extreme events. An advantage of the GEV approach is that it is possible to account for non-stationarity, from for example, external forcing (Zwiers et al., 2010), in a relatively straightforward manner. Examples of the types of block maxima considered in the application of EVT include the annual maximum amount of precipitation collected in a day or in 5-day periods (pentads), the annual peak flow in a river, or the highest annual temperature. In engineering practice, EVT is typically used to estimate design values from such series of extreme values. It is possible to estimate the magnitude of events that are unprecedented in the available record, say events that might be expected to occur once in a hundred or thousand years, though estimation for rarer events is associated with substantially higher uncertainty. Future changes in the intensity or frequency of extreme weather and climate events can also be evaluated this way. Studies based on EVT include, e.g., those by Zwiers and Kharin (1998), Kharin and Zwiers (2000), Frei et al., (2006), Laurent and Parey (2007), Della-Marta et al., (2007a), Kharin et al., (2007), Brown et al., (2008).

The complexity of the investigation of extremes and the requirement for high-quality data to diagnose changes in extreme events (see also Section 3.2.1) means that in practice one or other of the "extreme indices" or EVT approaches may be more appropriate depending on the data availability and research question being addressed. For many issues, they can be considered as complementary.

3.1.4. Compound (Multiple) Events

Much of the analysis of changes of extremes has, up to now, focused on individual extremes of a variable. However, the simultaneous or near-simultaneous occurrence of two or more extremes of several variables (e.g., high sea level coinciding with tropical cyclone landfall) or of the same variable (also referred to as clustered multiple events) can exacerbate the impact that would be suffered from the extreme events if they occurred in isolation (Box 3.4). Examples of clustered multiple events are for instance tropical cyclones or extratropical cyclones generated a few days apart with the same path and/or intensities, which may occur when there is persistence in atmospheric circulation and genesis conditions.

Compound events may also refer to the combination of two or more climate/weather events, which, individually, may not be considered extreme, but lead together to an extreme impact. An example is an above-average (but not extreme) rainfall event falling on above-average saturated soil, and thus leading to floods. Note that this may also be the result of a series of wet days resulting in saturated soils, followed by a further (possibly even average) event that, because of soil preconditioning, may lead to a disaster such as landslide, flooding, or even dam failure. Similarly, drought and heat extremes can lead in combination to changes in the possibility or intensity of forest and bush fires (see Chapter 4). As well, the near-simultaneous occurrence of two or more weather/climate events (e.g tropical cyclones) may also be considered "extreme", if such an occurrence is very rare.

In some cases, there might also be positive feedbacks between two types of extremes, which means that their simultaneous occurrence is not due to chance but to reinforcing mechanisms linking the two extremes (Section 3.1.5 and Box 3.4). In addition, it is also possible that the same region may be affected at the same time by different types of (unrelated) extremes ("contrasting events"), e.g., enhanced drought conditions and more frequent heavy rainfall (Box 3.4), which in combination lead to a much higher vulnerability of the region because it has to adapt simultaneously to changes in two opposite extremes. A more detailed discussion of compound events and how they may change with global warming is provided in Box 3.4. Despite their importance, neither the climate sciences nor the statistical sciences have yet developed adequate frameworks for characterizing such events and assessing whether their frequency and intensity is changing.

3.1.5. Impacts of Weather and Climate Events on the Physical Environment & Associated Feedbacks

Most atmospheric weather/climate events lead to the potential for disasters through their impacts on physical systems (soil moisture content, slope instability, erosion, sea level height) rather than their direct effects on humans or ecosystems. Examples include landslides or avalanches after heavy rains or snow, or forest fire after drought and heat waves. Thus it is important to consider how these different types of impacts are related to weather and climate (as also highlighted in Box 3.1, and in Section 3.5 for the individual considered impacts on the physical environment).

In addition, any changes in the physical environment may feed back into the weather/climate system. For instance, impacts on soil moisture availability are known to play a major part in controlling air temperature, boundary-layer development, precipitation formation and land carbon uptake (e.g., Betts, 2004; Koster et al., 2004b; Ciais et al., 2005; Seneviratne et al., 2006a; Reichstein et al., 2007; Seneviratne et al., 2010). They have also been suggested to impact monsoons in some regions (Grimm et al., 2007; Collini et al., 2008, see Section 3.4.1.2). Also, fires arising from drought might locally lead to pyrocumulus and heavy rain (Tryhorn et al., 2008). An example of a positive feedback between two types of extremes can be given for the case of droughts and heat waves in transitional climate regions, with heat waves leading to enhanced drought via enhanced evaporation, and drought conditions leading to enhanced temperature anomalies via decreased evaporative cooling (see also Box 3.4, and Sections 3.3.1 and 3.5.1). Despite these examples, there is still little literature on the role of feedbacks for the occurrence of extreme events and the interactions between different types of extremes.

Finally, it is important to note that impacts to ecosystems (Chapter 4) can also induce major feedbacks to the climate system, for instance through their modulation of soil moisture-climate feedbacks or through resulting impacts to the carbon cycle. Also socio-economic impacts (e.g., land use changes) can lead to (more indirect) feedbacks to the climate system.

START BOX 3.4 HERE

Box 3.4: Is it more Likely that in the Future Compound or Contrasting Extremes will Occur in the Same Region?

The close proximity in time of a drought followed by a flood in a specific region can have even more devastating impacts than would either extreme by itself. Most of this Chapter is devoted to assessing the literature regarding possible changes in the probability of occurrence of single extremes. The question of whether climate change may lead to changes in the probability of occurrence of pairs or groups of extremes occurring together, or at least close in time, is discussed in this Box.

Quantitative estimates of the probability that in the future more compound extremes will take place requires the determination of the degree to which the probability of occurrence of the separate events or their impacts are correlated or not, and whether this correlation may change in the future. Various causes for correlation between events and their impacts can be identified:

1. a common external forcing factor for changing the probability of the two events (e.g., regional warming)
2. mutual reinforcement of one event by the other and vice versa due to system feedbacks
3. dependence of the impact of one event on the occurrence of another one.

While relationships between events are obvious in the case of some related types of extremes (e.g., "wet extremes", i.e., heavy precipitation and floods), it is important to also consider the probability of mutual correlation between contrasting events (e.g., increased probability of both droughts and floods in the same region) and whether it may increase (or decrease) in the context of climate change. Indeed, it may be more difficult for society to adapt simultaneously to contrasting extremes, which may require more coping capacities than in the case of related extremes.

The erratic occurrence of extreme events, related to the inherent chaotic fluctuation of the climate system, usually limits our ability to assess the mutual correlation quantitatively. However, for each of the above categories some examples can be given to illustrate the conceptual picture.

Common external forcing

Many areas in the world are exposed to climate extremes of various origins, such as droughts, heat waves, intense precipitation, storm surges or hurricanes. Quantitative estimates of changes in the likelihood of simultaneous extreme events within a given region in response to global warming require a solid and common attributed link between the occurrence of the events and the anthropogenic effect on climate. However, apart from a few regional studies, a systematic assessment of regions where multiple climate extremes are subject to change in response to global warming has not been carried out.

At a regional level, Alexander and Arblaster (2009) explored projected changes of temperature and precipitation extremes in Australia using a multi-model approach. Although in their study model results show apparent deficiencies in reproducing many of the observed trends of climate extreme indices, consensus existed in projected increases in heat wave duration and warm nights, and consecutive number of dry days and heavy precipitation contribution. For example, the models projected increases in both heat wave duration and the consecutive number of dry days.

A more anecdotic example is reported by Lenderink et al., (2009), discussing the causal link between a strong temperature anomaly in the Netherlands and surroundings in July 2006, followed by record breaking heavy rainfall in the coastal area in August upon a sudden change of the regional atmospheric circulation picking up large amounts of moisture from the North Sea. Although rapid changes of weather regimes are common to most areas in the world, this case illustrates how a common external forcing (large scale heating due to a persistent atmospheric circulation) affected both the intensity of the heat wave in July and that of the extreme precipitation in the Dutch coastal region in response to high North Sea temperatures.

Another important dimension of a common external forcing is the change of the risk of extreme events in different regions that are unrelated with respect to their climate, but related with respect to their vulnerability. For instance, the dependence of agricultural production on El Niño in several countries of the world may give rise to a widespread (global) reduction of crop yield during El Niño/La Nina events. Thus, a change in the frequency or intensity of El Niño events could, simultaneously, affect the frequency of occurrence of droughts and floods in many parts of the world. A similar pattern of change could be caused by a change in the strength of the global or regional monsoons. It is for this reason that this Chapter examines the literature related to how a changing climate might affect the El Niño – Southern Oscillation and monsoons.

Mutual reinforcement due to feedbacks

Several studies have pointed out the various land-atmosphere feedback pathways that can give rise to regional low precipitation and drought conditions (Schubert et al., 2004; Schubert et al., 2008b; van Heerwaarden et al., 2009). In addition, the risk of extremely high temperatures and heat waves can increase during drought conditions due to lack of evaporative cooling, while the hot conditions also lead to a strengthening of the drought (Seneviratne et al., 2006a; Fischer et al., 2007a; Jaeger and Seneviratne, 2010). Persistence associated with soil moisture may also affect the persistence of heat waves, though this effect appears to be small (Lorenz et al., 2010). Due to the mutual feedbacks between temperature, evaporation, soil moisture and precipitation, the probability of droughts and heat waves to occur simultaneously is thus larger than for every individual event in regions where soil moisture can become a limiting factor for evapotranspiration (Koster et al., 2004b; Seneviratne et al., 2010).

Conditional occurrence or impact of individual events

Van den Brink et al., (2005) explored the simultaneous occurrence of sea level surges and high river discharge in the Netherlands using an archive of seasonal predictions from a recent episode. The closure of a dynamic storm surge barrier depends on the water level in the harbour behind the barrier, which in turn depends both on the sea level (including tidal and surge waves) and the discharge from the Rhine River. At high discharge rates the barrier needs to close at lower sea levels than for normal discharge conditions, to avoid flooding of the harbour. Both extreme events (storm surges and extreme river discharges) can be considered to be uncorrelated, but the common impact on the inland water level introduces an effective mutual dependence. The projected increased frequency of closure of the storm surge barrier is still mainly dependent on the mean sea level rise, and quantitative estimates of the effect of changes in the river discharge regime have yet to be made.

Another example of reinforcing extremes or their impacts is the impact of the severe southeast Australian bushfires of 7 February 2009, which occurred during a very prolonged drought. The drought led to drier fuels in forests, thus making conditions more conducive for bushfires.

Contrasting extremes

The factors discussed above may also apply to contrasting extremes. For instance, Christensen and Christensen (2003) and Trenberth et al., (2005) point out that a warmer climate may lead to an increased likelihood of extreme precipitation under warmer conditions but at the same time also be associated with increased risk of drought. A projected warming leads to an increase in potential evaporation, with increased risks of both agricultural drought (due to enhanced actual evapotranspiration and possible decrease in precipitation) and meteorological droughts (due to decreased relative humidity, seasonality of precipitation in, e.g., monsoon areas, or soil moisture-atmosphere feedbacks). Simultaneously, the frequency and intensity of heavy precipitation events may increase with temperature at a rate proportional to the Clausius Clapeyron relationship or higher, as verified by using observations by Lenderink and Van Meijgaard, (2008), due to latent heat release in the showers or other feedbacks. Thus, higher temperature gives rise to both an enhanced drought risk and a higher likelihood of intense precipitation. This apparent paradox is captured in many national climate change scenarios (e.g., van den Hurk et al., 2007). These cases can be seen as examples for mutual correlation due to a common forcing (enhanced greenhouse gas concentrations).

In some cases, contrasting extremes may also lead to mutual reinforcement, or at least a mutual dependence (points 2. and 3. above). Thus intense precipitation events can be triggered in response to strong convection of air that is heated and/or moistened near the surface. For instance, there is evidence that thunderstorms caused by bushfires (pyrocumulus) can lead to flash flooding (e.g., Tryhorn et al., 2008), due to induced heavy rainfall. Moreover the fires can cause modifications of soil characteristics, thereby increasing the possibility of flooding from the heavy rain. So a warming climate may, in such cases, lead to enhanced risk of these combinations of events.

Summary

In summary, it is difficult to give a definitive answer to the question of whether compound or contrasting events may be more likely in the future. The above anecdotic evidence does, however, suggest that new, surprising combinations of events are likely to occur. It should be noted as well that enhanced impacts from compound events can also occur due to increased vulnerability of a system to a given event due to the impact of another event, or because of increased exposure to a given event due to the impact of another event (and climate change may lead to such changes in vulnerability or exposure).

END BOX 3.4 HERE

3.2. Requirements and Methods for Analysing Changes in Extremes

3.2.1. Observed Changes

Sections 3.3 to 3.5 of this Chapter provide assessments of the literature regarding changes in extremes in the observed record published mainly since the AR4. Summaries of these assessments are provided in Table 3.1. Overviews of observed regional changes in temperature and precipitation extremes are provided in Figures 3.1. and 3.2., as well as in Table 3.2. In this sub-section issues are discussed related to the data and observations used to examine observed changes in extremes. This will allow the reader to place the results in later sections and their uncertainties in context with the data used to derive these results.

Issues with data availability are especially critical when searching for changes in extremes of given climate variables (Nicholls, 1995). Indeed, the more rare the event, the more difficult it is to identify long-term changes, simply because there are fewer cases to evaluate (Frei and Schär, 2001; Klein Tank and Können, 2003). Identification of changes in extremes is also dependent on the analysis technique employed (Zhang et al., 2004b; Trömel and Schönwiese, 2005). Trend analyses of extreme events may require data transformations for non-normally distributed data, and accounting for serial autocorrelation in climate time series (Smith, 2008). To avoid excessive statistical limitations, trend analyses of extremes have traditionally focused on standard and robust statistics that describe moderately extreme events that occur a few times a year (see also Section 3.1.3).

Another important criterion constraining data availability for the analysis of extremes is the respective time scale on which they occur (Sections 3.1.1.1. and 3.1.3), since this determines the required temporal resolution for their assessment (e.g., heavy hourly or daily precipitation versus multi-year drought). Longer time resolution data (e.g., monthly, seasonal, and annual values) for temperature and precipitation are available for most parts of the world starting late in the 19th to early 20th century, and allow analysis of (meteorological) drought and unusually wet periods on the order of a month or longer. Most meteorological records before the 17th century consist of testimonies of extreme events that affected society and hence stuck in people's memories (Le Roy Ladurie, 1971; Heino et al., 1999). To examine changes in extremes occurring on short time scales, particularly of climate elements such as temperature and precipitation, normally requires the use of high-temporal resolution data, such as daily or sub-daily observations, which are generally either not available, or available only since the middle of the 20th century and in many regions only from as recently as 1970.

Where data are available, several problems can still limit the analysis of observations. First, although the situation is changing, many countries still do not freely distribute their higher temporal resolution data. Second, there can be issues with the quality of measurements. A third important issue is climate data homogeneity. The last two items are addressed in more detail in the following paragraphs.

Regarding the quality of measurements, long-term observations of climate are often available only at weather stations, such as at airports, that were designed to take observations in support of developing weather forecasts, and not for climate purposes, and this can result in lower quality data. Another problem affecting precipitation measurements is the undercatch of rain gauges, especially in winter (e.g., Sevruk, 1996; Yang et al., 2005). Furthermore, there are a number of data problems that can affect values that exceed thresholds, and are thus most relevant to the analysis of extremes. Quality control procedures designed to flag a value suspected of being erroneous can impact the research results by flagging extreme values that are truly correct, or by not flagging a truly incorrect value. This can happen in particular in the case of large daily precipitation totals associated with convective storms, or in the case of an isolated extreme temperature event. Quality assurance checks are typically implemented to examine the data on a station-by-station basis. These employ both internal checks, such as climatological bounds checks (e.g., is the value reasonable for the location and season), and spatial checks using comparison with nearby climate stations. An isolated but intense thunderstorm may result in an extreme daily precipitation total at one station, but not impact any surrounding stations and thus result, incorrectly, in a flagged value. In recent years particular care has been given to develop automated quality assurance procedures that minimize the flagging of valid observations (false positives), but do remove the truly incorrect values (Durre et al., 2008).

Whether or not climate data are homogeneous can also significantly impact the results of an analysis of extremes. Data are defined as homogeneous when the variations and trends in a climate time series are due solely to variability and changes in the climate system. Inhomogeneities occur in a climate time series due to a variety of reasons. These include changes in the location of an observing station (Trewin, 2010), changes in instrumentation (e.g., the introduction of the Stevenson Screen) (e.g., Nicholls et al., 1996), the installation or removal of a wind shield on a precipitation gauge, land use/land cover changes, or changes in the daily observing time. Some meteorological elements are especially vulnerable to uncertainties caused by even small changes in the exposure of the measuring equipment. For instance, erection of buildings or changes in vegetative cover can produce a bias in wind measurements. When a change occurs it can result in either a discontinuity in the time series (slight jump) or a more gradual change that can manifest itself as a false trend (Menne and Williams Jr., 2009), both of which can impact on whether a particular observation exceeds a threshold. Homogeneity detection and data adjustments have been implemented for longer averaging periods (e.g., monthly, seasonal, annual); however homogeneity detection and adjustments for daily and sub-daily data are only now being developed (e.g., Vincent et al., 2002; Della-Marta and Wanner, 2006), and have not been widely implemented.

With respect to temperature and precipitation measurements, the above mentioned issues have been partly addressed in the past 15 years. However, they still affect the monitoring of other meteorological and climate variables, for which further and more severe limitations also can exist. This is in particular the case regarding measurements of wind and relative humidity, and data required for the analysis of weather and climate phenomena (tornadoes, extra-tropical and tropical cyclones, Section 3.4), as well as impacts on the physical environment (e.g., droughts, floods, cryosphere impacts, Section 3.5).

Thunderstorms and tornadoes are not well observed in many parts of the world. Tornado occurrence since 1950 in the USA., for instance, displays an increasing trend that mainly reflects increased population density and increased numbers of people in remote areas (Trenberth et al., 2007; Kunkel et al., 2008). Such trends increase the likelihood that a tornado would be observed. A similar problem occurs with thunderstorms. Changes in reporting practices, increased population density and even changes in the ambient noise level at an observing station all have led to inconsistencies in the observed record of thunderstorms.

Studies examining changes in extra-tropical cyclones (ETCs), which focus on changes in storm track location, intensities and frequency, are limited in time due to a lack of suitable data prior to about 1950. Most of these studies have relied on model-based reanalyses that also incorporate observations into a hybrid model-observational data set. However, reanalyses can have homogeneity problems due to changes in the amount and type of data being assimilated, such as the introduction of satellite data in the late 1970s and other observing system changes (Trenberth et al., 2001; Bengtsson et al., 2004). Recent efforts in reanalysis have attempted to produce more homogeneous reanalyses that show promise for examining changes in ETCs and other climate features (Compo et al., 2006).

The robustness of analyses of observed changes in tropical cyclones has been hampered by a number of issues with the historical record. One of the major issues is the heterogeneity introduced by changing technology and reporting protocols within the responsible agencies (e.g., Landsea et al., 2004). Further heterogeneity is introduced when records from multiple ocean basins are combined to explore global trends, because data quality and reporting protocols vary substantially between agencies (Knapp and Kruk, 2010). Much like other weather and climate observations, tropical cyclone observations are taken to support short-term forecasting needs. Improvements in observing techniques are often implemented without any overlap or calibration against existing methods to document the impact of the changes on the climate record. Additionally, advances in technology have enabled better and more complete observations. For example, the introduction of aircraft reconnaissance in the 1940s and satellite data in the 1960s had a profound effect on our ability to accurately identify and measure tropical cyclones, particularly those that never encountered land or a ship. While aircraft reconnaissance programs have continued in the Atlantic, they were terminated in the Western Pacific in 1987. The introduction of geostationary satellite imagery in the 1970s, and the introduction (and subsequent improvement) of new tropical cyclone analysis methods (such as the Dvorak technique for estimating storm intensity), further compromises the homogeneity of historical records of tropical cyclone activity.

Regarding impacts to the physical environment, soil moisture is a key variable for which data sets are extremely scarce (e.g., Robock et al., 2000; Seneviratne et al., 2010). This represents a critical issue for the validation and correct representation of (agricultural as well as hydrological) drought mechanisms in climate, land surface and hydrological models, and the monitoring of on-going changes in regional terrestrial water storage. As a consequence, these need to be inferred from simple climate indices or model-based approaches (e.g., Heim Jr, 2002; Dai et al., 2004; Sheffield and Wood, 2008). Such estimates rely in large part on precipitation observations, which have, however, inadequate spatial coverage for these applications in many regions of the world (e.g., Oki et al., 1999; Fekete et al., 2004; Koster et al., 2004a). Similarly, runoff observations are not globally available, which results in significant uncertainties in the closing of the global and some regional water budgets (Legates et al., 2005; Peel and McMahon, 2006; Dai et al., 2009; Teuling et al., 2009), as well as for the global analysis of changes in the occurrence of floods. Additionally, ground observations of snow, which are lacking in several regions, are important for the investigation of several physical impacts, in particular those related to the cryosphere and runoff generation (e.g., Essery et al., 2009; Rott et al., 2010).

All of the mentioned issues lead to uncertainties in observed trends in extremes. In many instances, great care has been taken to develop procedures to improve the data which in turn helps to reduce uncertainty. Progress has been in particular achieved in the last 15 years, partly in response to previous IPCC assessments that strongly highlighted these problems. As a consequence, more complete and homogenous information about changes is now available for at least some variables and regions (Nicholls and Alexander, 2007; Peterson and Manton, 2008). For instance, the development of global data bases of daily temperature and precipitation covering up to 70% of the global land area, has allowed robust analyses of extremes (c.f., Alexander et al., 2006). These global analyses of temperature and precipitation extremes (e.g., Alexander et al., 2006) are consistent with what would be expected from analyses of mean values using homogeneity-adjusted data (e.g., Vose et al., 2005), which provides more confidence in the results (although such consistency may not necessarily be expected for all extremes at all locations, see Box 3.3.). In addition, analyses of temperature and precipitation extremes using higher temporal resolution data, such as that available in the Global Historical Climatology Network-Daily data set (Durre et al., 2008) have also proven robust on both a global (Alexander et al., 2006) and regional basis (Sections 3.3.1 and 3.3.2). Nonetheless, as highlighted above, for many extremes, data remain sparse and problematic resulting in less ability to establish changes particularly on a global basis.

The AR4 (Trenberth et al., 2007) cited a lack of data sets available to determine long-term trends in many climate extremes. In many instances this is still the case for some variables such as wind, for small-scale phenomena such as tornadoes or hail, and also for diagnosing changes in agricultural droughts (soil moisture). For some extremes more and improved data sets have become available or have been more thoroughly analysed, since the AR4. Changes in unusually warm nights and days and in unusually cold nights and days, and heat waves since the middle of the 20th century have been now documented in more regions than were possible for the AR4. The same is true for changes in heavy and extreme precipitation events and for meteorological drought. There is more evidence for shifts in extra-tropical cyclone storm tracks and changes in intensity of these storms. However, recent developments in tropical cyclone research have led to increased uncertainty regarding past changes in tropical cyclone activity, particularly in the period before widespread satellite observations.

INSERT FIGURE 3.1 AND FIGURE 3.2 HERE

Figure 3.1: Regional observed changes in temperature and precipitation extremes (Americas)

Figure 3.2: Regional observed changes in temperature and precipitation extremes (Europe, Africa, Asia and Oceania). See Figure 3.1 for definition of symbols

INSERT TABLE 3.2 HERE

Table 3.2: Regional observed changes in temperature and precipitation extremes. Assessments for which no likelihood statements are available yet are displayed in grey in the Table (empty arrows on Figures 3.1 and 3.2).

3.2.2. The Causes Behind the Changes

3.2.2.1. Why Extremes Change and What are the Possible Causes

This section addresses the question of the attribution of causes for observed or projected changes in extremes. In Sections 3.3. to 3.5, the causes for observed changes in the evaluated extremes are assessed. A summary of these assessments is provided in Table 3.1.

Climate variations and change are induced both by the chaotic nature of the climate system (natural internal variability), and by changes in external forcings, which include natural external forcings such as changes in solar irradiance and volcanism, and anthropogenic forcings such as increased greenhouse gas emissions principally due to the burning of fossil fuels (but also air pollution and land use changes). At the global scale, it has been established by the AR4 that most of the observed increase in global mean surface temperatures since the mid-20th century is *very likely* due to the increase in greenhouse gas concentrations (Hegerl et al., 2007). On regional scales, variability internal to the climate system may play a larger role than on global scales. However, there is evidence of human influence on regional temperatures as well, at least in some regions (Stott et al., 2004; Zhang et al., 2006; Zwiers et al., 2010). Since the AR4, the effects of external forcing on changes on the hydrological cycle (Stott et al., 2010, see also Section 3.2.2.2), and on the cryosphere (Min et al., 2008b) have also been detected. The warming is expected to continue in the foreseeable future even if there is no additional increases to greenhouse gases in the atmosphere ("committed warming"), due both to the long atmospheric half-life of CO_2 and the thermal inertia of the oceans (IPCC, 2007b) although the rate of warming will reduce rapidly if atmospheric CO_2 concentrations are reduced (Matthews and Weaver, 2010). Given the impact of enhanced greenhouse gas concentrations on the climate as a whole, extremes are expected to change as well.

A diagnosed trend or change in extremes can either be the result of changes in external forcing, or a manifestation of the natural internal variability of the climate system, or a combination of the two. With scarce data (as is the case for extremes, see Section 3.2.1) and for relatively short-term trends, it can be challenging to distinguish between these two alternative explanations, which is clearly of key relevance for climate change attribution. For this latter question, one also needs to distinguish between the effects of anthropogenic and natural forcings.

When addressing the causes of diagnosed changes in climate mean and extremes at various locations, an additional dimension to be considered is the role of feedbacks and interactions between processes for these resulting changes (Section 3.1.5), and their links to external forcings. There are still many uncertainties in modelling these interactions. As well, there is still a lack of data on regional external forcing such as land use changes, and the mechanisms that cause observed changes may not be fully represented in model simulations. These factors can further complicate attribution of regional climate changes, and especially of extremes.

Since it is impossible to experiment with the real atmosphere to determine the roles of different external forcings on the climate system, our main source of information on the climate response to external forcings in the past and for the future is climate model simulations. Our understanding of how the extremes have responded to external forcings in the past, and how they will respond in the future, also needs to come from climate model simulations, either directly or indirectly (using e.g., sensitivity experiments, see also Section 3.2.2.3). Therefore, we need to use climate model simulations, together with observations, to understand the causes behind the changes in extremes.

3.2.2.2. Human-Induced Changes in the Mean Climate that Affect Extremes

The occurrence of extremes is usually the result of multiple factors, which can act either on the large scale or on the regional (and local) scale. Some relevant large-scale impacts of global warming affecting extremes include the overall changes in temperature induced by enhanced radiation forcing, the enhanced humidity content of the atmosphere (linked with the Clausius-Clapeyron relationship), the increased land-sea contrast in temperatures, which can, e.g., affect circulation patterns and in particular monsoons. On the regional and local scales, other processes can contribute to modulate the overall changes in extremes, in particular land-atmosphere interactions (e.g., Seneviratne et al., 2006a). A detectable change in the mean climate can be a strong indication of a change in extremes in some circumstances (Gutowski et al., 2008b) (Box 3.3).This section briefly reviews the current understanding of the causes of large-scale (and some regional) changes in the mean climate that are of relevance to extreme events, to the extent that they have been considered in detection and attribution studies.

Regarding observed increases in global average annual mean surface temperatures since the mid-20th century, the AR4 concluded that they are *very likely* due for the most part to observed increase in anthropogenic greenhouse gas concentrations. Anthropogenic warming was also detected in the troposphere and in the global oceans. Greenhouse gas forcing alone during the past half century would likely have resulted in a greater warming than observed if there had not been an offsetting cooling effect from aerosol and other forcings. It is *extremely unlikely* (<5%) that the global pattern of warming during the past half century can be explained without external forcing, and *very unlikely* that it is due to known natural external causes alone. The warming took place at a time when natural external forcing factors such as solar output would likely have produced cooling. At sub-global scale, anthropogenically-forced warming over the past 50 years has also been detected in all continents (Hegerl et al., 2007; Gillett et al., 2008b).

Overall, attribution at scales smaller than continental, with limited exceptions (e.g., Barnett et al., 2008), has still not yet been established primarily due to the low signal-to-noise ratio and the difficulties of separately attributing effects of the wider range of possible forcings at these scales. Averaging over smaller regions reduces the natural variability less than does averaging over large regions, making it more difficult to distinguish between changes expected from different external forcings, or between external forcing and natural variability. Temperature changes associated with some modes of variability are poorly simulated by models in some regions and seasons. In addition, the small-scale details of external forcing, and the response simulated by models are less credible than large-scale features. Furthermore, the inclusion of additional forcing factors, such as land-use change and aerosols that are likely more important at regional scales, remains a challenge (Lohmann and Feichter, 2007; Pitman et al., 2009; Rotstayn et al., 2009). Because of these, regional scale detection is still hard to achieve.

Nonetheless, recent work has expanded the literature in addressing the detection and attribution of changes in climate at smaller spatial scales and for seasonal averages (Stott et al., 2010). For instance, Min and Hense (2007) assessed the consistency between observed changes in surface temperature over six populated continents and several alternative proposed explanations for those changes, including influence of anthropogenic and natural external forcing, and internal variability of the climate system, based on a Bayesian decision theory. They found that anthropogenic forcing was required for most continent-season cases to best match the observed changes. Jones et al., (2008) examined summer (June-August) mean temperatures over the past century over a set of sub-continental regions of the Northern Hemisphere. When signals were regressed individually against the observations, an anthropogenic signal was detected in each of 14 regions except for one, central North America, although the results were more uncertain when anthropogenic and natural signals were considered together. Burkholder and Karoly (2007) detected an anthropogenic signal in multi-decadal trends of a U.S. climate extreme index and Dean and Stott (2009) detected a signal in New Zealand temperatures. While these new studies provide more evidence of anthropogenic influence at increasingly smaller spatial scales, they have not significantly changed the AR4 assessment on attributing regional temperature change to causes (Hegerl et al., 2007).

One of the significant advances since AR4 is the emerging evidence of human influence on global atmospheric moisture content and precipitation. According to the Clausius-Clapeyron relationship, the saturation vapor pressure increases exponentially with temperature. Since moisture condenses out of supersaturated air, it is physically plausible that the distribution of relative humidity would remain roughly constant under climate change. Observations also seem to suggest relatively constant relative humidity on climatological time scales (Peixoto and Oort, 1992). This means that specific humidity increases about 7% for a one degree increase in temperature. Indeed, observations indicate significant increases between 1973 and 2003 in global surface specific humidity but not in relative humidity (Willett et al., 2008), consistent with the Clausius-Clapeyron relationship. Anthropogenic influence has been detected in the global surface specific humidity for 1973–2003 (Willett et al., 2007), and in lower tropospheric moisture content over the 1988–2006 period (Santer et al., 2007). A comparison of observed precipitation trends over two periods during the 20th century averaged over latitudinal bands over land with those simulated by fourteen climate models forced by the combined effects of anthropogenic and natural external forcing, and by four climate models forced by natural forcing alone detected the influence of anthropogenic forcing (Zhang et al., 2007a). While these changes cannot be explained by internal climate variability or natural forcing, the magnitude of change in the observations is greater than those simulated. Furthermore, evidence from measurements in the Netherlands suggest that hourly precipitation extremes may in some cases increase more strongly with temperature (twice as fast) than would be assumed from the Clausius-Clapeyron relationship alone (Lenderink and Van Meijgaard, 2008). The influence of anthropogenic greenhouse gases and sulphate aerosols on changes in precipitation over high-latitude land areas north of 55°N has also been detected (Min et al., 2008a). Detection is possible here, despite limited data coverage, in part because the response to forcing is relatively strong in the region, and because internal variability is low in this region.

3.2.2.3. How to Attribute Causes to a Change in Extreme

The causes of climate change have been assessed based on climate change detection and attribution approaches (Santer et al., 1996; Mitchell et al., 2001; Hegerl et al., 2007; Hegerl et al., 2010). The attribution of causes to change in extremes may be assessed similarly. Recent discussion during the joint Expert Meeting of IPCC WGI/WGII has resulted in a set of definitions and terminologies on detection and attribution for both Working Groups. The resulting guidance paper on detection and attribution (Hegerl et al., 2010) has the following definitions on detection and attribution. 'Detection' of change is defined as the process demonstrating that climate or a system affected by climate has changed in some defined statistical sense without providing a reason for that change. 'Attribution' is the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of confidence. Attribution involves careful assessment of observed changes in relation to those that are expected to have occurred in response to external forcing, typically as simulated by climate models.

There are different approaches to attribution problems but single-step attribution and multi-step attributions are most often used in climate literature. Single-step attribution to external forcings involves assessments that attribute an observed change within a system to an external forcing based on explicitly modelling the response of the variable to the external forcings. Modelling can involve a single comprehensive model or a sequence of models. Multi-step attribution to external forcings comprises assessments that attribute an observed change in a variable of interest to a change in climate, plus separate assessments that attribute the change in climate to external forcings. In this case, confidence in the attribution cannot be higher than the lower confidence in the two assessment steps.

Attribution of changes in climate extremes has been a considerable challenge due to several factors. Observed data are limited in both quantity and quality (Section 3.2.1), resulting in uncertainty in the estimate of past changes; the signal-to-noise ratio may be low for many variables and insufficient data may be available to detect such weak signals. Global climate models may not simulate some extremes such as tropical cyclones with reasonable fidelity or may not simulate some other extremes such as small spatial scale floods at all. For some extremes (e.g., agricultural drought), too little observational data may be available to assess the model performance. In addition, differences in the spatial scale of extremes from the observations and from the model simulations also make it difficult to compare observations with model simulations. For example, climate models operate on model grids much larger than an area typically represented by an in-situ observation site. On the one hand, models are not able to produce point estimate of extremes such as the annual maximum amount of daily precipitation at an observational site; on the other hand, the limited availability of observation stations in many parts of the world makes it impossible to produce accurate estimates of area-averaged daily precipitation at model resolutions; furthermore, the scale of resolved motions may not allow a model to simulate the circulation features that produce intense precipitation in the real world.

Post-processing of climate model simulations to derive a quantity of interest that is not explicitly simulated by the models, by applying empirical methods or physically-based models to the outputs from the climate models, may alleviate this problem, and make it possible to conduct single-step detection and attribution assessment. For example, model-simulated sea level pressure has been used to derive geostrophic wind to represent atmospheric storminess and to derive significant wave height on the oceans for the detection of external influence on trends in atmospheric storminess and northern oceans wave heights (Wang et al., 2009c). Barnett et al., (2008) downscaled GCM-simulated precipitation and temperature data as input to hydrological and snow depth models to infer past and future changes in temperature, timing of the peak flow, and snow water equivalent for the western U.S., and then conducted a detection and attribution analysis on human-induced changes in these variables.

A single-step attribution of cause and effect on extremes or physical impacts of extremes may not always be possible. When this is the case, multiple-step attribution may still be feasible. The assessment would then need to be based on indirect evidence, physical understanding and expert judgement, or a combination of these. For instance, in the northern high latitude regions, spring temperature has increased, and the timing of spring peak floods of snowmelt rivers has shifted towards earlier dates (Zhang et al., 2001; Regonda et al., 2005). The change in streamflow may be attributable to anthropogenic influence if streamflow regime change can be attributed to a spring temperature increase and if the spring temperature increase can be attributed to external forcings. In such a case, it may not be possible to quantify the magnitude of the effect of external forcing on flow regime change because a direct link between the two has not been established, so the confidence in the overall assessment would be similar to or weaker than the lower confidence in the two steps in the assessment. The physical understanding that snow melts earlier as spring temperature increases, enhances our confidence in the assessments. A necessary condition for multi-step attribution is to establish the chain of mechanisms responsible for the specific extremes being considered. Physically-based process studies and sensitivity experiments that help the physical understanding can play an important role in such cases (e.g., Findell and Delworth, 2005; Seneviratne et al., 2006a; Haarsma et al., 2009). These can allow the distinction of the influence on extremes from different drivers that may, in turn, be influenced by external forcings.

Extreme events are by definition rare, which means that there are also few data available to make an assessment (Section 3.2.1). When a rare and catastrophic meteorological extreme event occurs, a question that is often posed is whether such an event is due to anthropogenic influence. Because it is very difficult to rule out the occurrence of low probability events in an unchanged climate and the occurrence of such events usually involves multiple factors, it is very difficult to attribute an individual event to specific causes (Allen, 2003; Hegerl et al., 2007, see also FAQ 3.2). However, in this case, it may be possible to estimate the influence of external forcing on the likelihood of such an event occurring. For example, Stott et al., (2004) detected anthropogenic influence on mean summer temperature in southern Europe; they then estimated the effect of anthropogenic forcing on the likelihood of a warm summer, and finally inferred an anthropogenic influence on the likelihood of the 2003 European heat wave. A similar approach has been applied to estimate the contribution of anthropogenic greenhouse gas emissions to the England & Wales autumn 2000 flood probability (Pall et al., 2010).

START FAQ 3.2 HERE

FAQ 3.2: Can we Attribute Individual Extreme Events to Climate Change?

Changes in climate extremes are expected as the climate warms in response to increasing atmospheric greenhouse gases resulting from human activities, such as the use of fossil fuels. However, determining whether a specific, single extreme event is due to increasing greenhouse gases, is difficult, if not impossible, for two reasons: 1) a wide range of extreme events occur normally even in an unchanging climate, and 2) extreme events are usually caused by a combination of factors, most of which would not be directly related to changing atmospheric composition. Nevertheless, analysis of the warming observed over the past century suggests that the likelihood of some extreme events, such as heat waves, has increased due to greenhouse warming, and that the likelihood of others, such as frost or extremely cold nights, has decreased. For example, it has been estimated that human influences have more than doubled the probability of a very hot European summer like that of 2003.

People affected by an extreme weather events often ask whether human influences on the climate could be held to some extent responsible. Recent years have seen many extreme events that some commentators have linked to increasing greenhouse gases. These include the prolonged drought in Australia, the extremely hot summer in Europe in 2003, the intense North Atlantic hurricane seasons of 2004 and 2005 and the extreme rainfall events in Mumbai, India in July 2005, and the historically warmest January and February in Vancouver, Canada that affected 2010 Winter Olympic Games. Could a human influence such as increased concentrations of greenhouse gases in the atmosphere have 'caused' any of these events?

FAQ 3.2, Figure 1 shows the distribution of monthly mean November temperatures averaged across the State of New South Wales in Australia, using data from 1950-2009. The mean temperature for November 2009 (the bar on the far right hand end of the Figure) lies about 3.5 standard deviations above the 1950-2008 mean. A simple statistical calculation suggests that there is perhaps less than one chance in a thousand that such a temperature would be observed in the 1950-2008 climate, and the 2009 temperature certainly looks unusual in the Figure, relative to the other years plotted there. Is this rare occurrence an indication of changing climate? In the CRUTEM3V global land surface temperature data set, about one in every 1000 monthly mean temperatures observed between 1900 and 1949 lies more than 3.5 standard deviations above the corresponding monthly mean temperature for 1950-2008[1]. Since global temperature was lower in the first half of the 20th century, this clearly indicates that an extreme warm event as rare as the 2009 November temperature in New South Wales could have occurred in the past during a period when the effects of greenhouse gas increases were much less pronounced. A similar calculation shows that a warm month as extreme as June, 2003 in Switzerland was also not without precedent during the first half of the 20th century, although in that case, only about one in every 13000 monthly means was as extreme.

A second complicating factor is that extreme events usually result from a combination of factors, and this will make it difficult to attribute an extreme to a single causal factor. For example, several factors contributed to the extremely hot European summer of 2003, including a persistent high-pressure system that was associated with very clear skies and dry soil, which left more solar energy available to heat the land because less energy was consumed to evaporate moisture from the soil. Similarly, the formation of a hurricane requires warm SSTs and specific atmospheric circulation conditions. Because some factors may be strongly affected by human activities, such as SSTs, but others may not, it is not simple to isolate a human influence on a single, specific extreme event.

Nevertheless, it may be possible to use climate models to determine whether human influences have changed the likelihood of certain types of extreme events. For example, in the case of the 2003 European heat wave, a climate model was run including only historical changes in natural factors that affect the climate, such as volcanic activity and changes in solar output. Next, the model was run again including both human and natural factors, which produced a simulation of the evolution of the European climate that was much closer to that which had actually occurred. Based on

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[1] We used the CRUTEM3V land surface temperature data. We limit our calculation to grid points with long-term observations, requiring at least 50 non-missing values during 1950-2008 for a calendar month and a grid point to be included. A standard deviation is computed for the period 1950-2008. We then count the number of occurrences when the temperature anomaly during 1900-1949 relative to 1950-2008 mean is greater than 3.5 standard deviation, and compare it with the total number of observations for the grid and month in that period. The ratio between these two numbers is 0.00107.

these experiments, it was estimated that over the 20th century, human influences more than doubled the likelihood of having a summer in Europe as hot as that of 2003, and that in the absence of human influences, the probability would probably have been one in many hundred years. More detailed modelling work will be required to estimate the change in likelihood for specific high-impact events, such as the occurrence of a series of very warm nights in an urban area such as Paris.

INSERT FAQ 3.2, FIGURE 1 HERE

FAQ 3.2, Figure 1: The distribution of monthly mean November temperatures averaged across the State of New South Wales in Australia, using data from 1950–2009. Data from Australian Bureau of Meteorology. The mean temperature for November 2009 (the bar on the far right hand end of the Figure) was more than three standard deviations from the long-term mean (calculated from 1950–2008 data).

The value of such a probability-based approach – 'Does human influence change the likelihood of an event?' – is that it can be used to estimate the influence of external factors, such as increases in greenhouse gases, on the frequency of specific types of events, such as heat waves or cold extremes. Nevertheless, careful statistical analyses are required, since the likelihood of individual extremes, such as a late-spring frost, could change due to changes in climate variability as well as changes in average climate conditions. Such analyses rely on climate-model based estimates of climate variability, and thus the climate models used should adequately represent that variability. The same likelihood-based approach has been used to examine anthropogenic greenhouse gas contribution to flood probability.

Finally, it should be remembered that the discussion above relates to an individual, specific occurrence of an extreme event (e.g., a single heat wave). For the reasons outlined above it remains very difficult to attribute any individual event to greenhouse gas induced warming (even if physical reasoning or model experiments suggest such an extreme may be more likely in a changed climate). However, a long-term trend in an extreme (e.g, heatwave occurrences), especially if observed at many locations, is a different matter. It is certainly feasible, in these circumstances, to test whether such a trend is likely to have resulted from anthropogenic influences on the climate, just as a global warming trend can be assessed to determine its likely cause.

END FAQ 3.2 HERE

3.2.3. Projected Long-Term Changes and Uncertainties

In this sub-section we discuss the requirements and methods used for preparing climate change projections, with a clear focus on projections of extremes and the associated uncertainties. Much of the discussion is based closely on AR4 (Christensen et al., 2007) with consideration of some additional issues relevant to projections of extremes in the context of risk and disaster management. More detailed assessment of projections for specific extremes is provided in Sections 3.3 to 3.5. Summaries of these assessments are provided in Table 3.1. Overviews of projected regional changes in temperature and precipitation extremes are provided in Figures 3.3. and 3.4. as well as in Table 3.3.

3.2.3.1. Information Sources for Climate Change Projections

Work on the construction, assessment and communication of climate change projections, including regional projections and of extremes, typically draws on information from four sources: Atmosphere-Ocean General Circulation Model (AOGCM) simulations; downscaling of AOGCM-simulated data using techniques to enhance regional detail; physical understanding of the processes governing regional responses; and recent historical climate change. At the time of the AR4, AOGCMs were the main source of globally-available regional information on the range of possible future climates including extremes (Christensen et al., 2007). A clearer picture of the more robust aspects of regional climate change was, however, emerging at that time, due to improvements in model resolution, more credible simulations of processes of importance for regional change, the availability of more and better historical climate data, and the availability of an expanding set of global simulations.

State-of-the-art AOGCMs are based on physical laws and processes expressed as equations, which the model represents on a grid and integrates forward in time. Processes with scales too small to be resolved on the spatial scale of the model grid are represented through modules based on observations and physical theory called parameterizations. This is partly due to limitations in computing power, but also results from limitations in scientific understanding or in the availability of detailed observations of some physical processes and parameters (relevant for e.g., cloud-aerosol interactions or land-atmosphere exchanges). AOGCMs show significant and improving skill in representing many important average climate features, and even essential aspects of many of the patterns of climate variability observed across a range of time scales. This makes them 'fit for purpose' for many applications. However, when we wish to project climate and weather extremes, not all atmospheric phenomena potentially of relevance can be realistically simulated using these global models and the development of projections of extreme events has provided one of the motivations for the development of regionalisation or downscaling techniques (Carter et al., 2007).

Downscaling techniques have been specifically developed for the study of regional- and local-scale climate change. Downscaling is the use of high-resolution dynamical models or statistical techniques to simulate weather and climate at finer spatial resolutions than is possible with AOGCMs – a step which is particularly relevant for many extremes given their spatial scale (e.g., convective events and wind gusts, see also Section 3.2.1). All downscaling approaches are, nonetheless, constrained by the reliability of large-scale information coming from the AOGCMs. Recent advances in downscaling for extremes are discussed below. However, as global models continue to develop, and their spatial resolution continues to improve, they are becoming increasingly useful for investigating important smaller-scale features, including changes in extreme weather events, and further improvements in regional-scale representation are expected with increased computing power (though it should not be assumed that greater resolution necessarily translates into greater credibility of projections).

There are two main downscaling approaches, dynamical and statistical (Christensen et al., 2007). The most common approach to dynamical downscaling uses high-resolution regional climate models (RCMs), currently at scales of 20km-50km, but in some cases down to 10-15km (e.g., Dankers et al., 2007), to represent regional sub-domains, using either observed (reanalysis) or lower-resolution AOGCM data to provide their boundary conditions (i.e., the atmospheric behaviour on the boundaries of the sub-domain). Using non-hydrostatic mesoscale models, applications at 1-2km resolution are also possible for shorter periods (typically a few months, a few years at most) – a scale at which clouds and convection can be resolved (e.g., Grell et al., 2000; Hay et al., 2006; Hohenegger et al., 2008). For the higher-resolution simulations (i.e., < 10-20km), double-nesting may be required (i.e., embedding of very high-resolution simulations within coarser-scale RCM simulations). Less-commonly used approaches to dynamical downscaling involve the use of stretched-grid (variable resolution) models and high-resolution 'time-slice' models (e.g., Cubasch et al., 1995; Gibelin and Deque, 2003; Coppola and Giorgi, 2005; CCSP, 2008). The main advantage of dynamical downscaling is its potential for capturing mesoscale nonlinear effects and providing information for many climate variables while ensuring that such information is internally consistent within the physical constraints of the model. As in the case of AOGCMs, RCMs are formulated using physical principles and they can credibly reproduce a broad range of climates around the world, which increases confidence in their ability to realistically downscale future climates. For many users, the main drawbacks of dynamical models are their computational cost and that they do not provide information at the point (i.e., weather station) scale (a scale at which the RCM parameterizations would not work).

Statistical downscaling methods use cross-spatial-scale relationships that have been derived from observed data, and apply these to climate model data (Christensen et al., 2007). They also include weather generators which provide the basis for a number of recently-developed user tools that can be used to assess changes in extreme events (Kilsby et al., 2007; Burton et al., 2008; Qian et al., 2008; Semenov, 2008). Statistical downscaling has been demonstrated to have potential in a number of different regions including Africa (e.g., Hewitson and Crane, 2006), Australia (e.g., Timbal et al., 2008; Timbal et al., 2009), South America (e.g., D'Onofrio et al., 2010) and Canada (e.g., Dibike et al., 2008). Statistical downscaling methods have the advantage to users of being computationally inexpensive, potentially able to access finer spatial scales than dynamical methods and applicable to parameters that cannot be directly obtained from the RCM outputs. Seasonal indices of extremes can, for example, be simulated directly without having to first produce daily time series (Haylock et al., 2006a). Although based on statistical relationships rather than physical laws, the reliability of statistical downscaling methods can be explored by assessing their ability to reproduce shifts in the observed climate (i.e., to reproduce non-stationary climates). Statistical models can, for example, reproduce the observed rainfall decline in the late 1960s in the southwest of Australia (Timbal, 2004) and in the mid-1990s in the southeast of Australia (Timbal and Jones, 2008). However, they require observational data at the desired scale (e.g., the point or station scale) for a long enough period to allow the model to be well trained and validated (thus minimising problems of stationarity), and in some methods, can lack coherency among multiple climate variables and/or multiple sites. In the case of downscaling extremes, one specific disadvantage of some statistical methods is that they cannot produce events greater in magnitude than have been observed before (Timbal et al., 2009). In addition, both present-day performance and the projected climate change can be very sensitive to the choice of predictors.

There have been rather few systematic inter-comparisons (in terms of both their ability to simulate present-day climate and their projected changes) of dynamical and statistical downscaling approaches, particularly inter-comparisons focusing on extremes (Fowler et al., 2007a). Two examples focus on extreme precipitation for the UK (Haylock et al., 2006a) and the Alps (Schmidli et al., 2007), respectively. The latter study indicates that the best statistical methods can reproduce the magnitude of the observed extremes with similar skill to the RCMs, but underestimate interannual variability. For users of downscaled information, the identification and selection of appropriate methods for impact assessment and adaptation planning may depend on factors such as ease of accessibility, resource requirements and type of output, as much as performance (Fowler et al., 2007a; Wilby et al., 2009).

3.2.3.2. Uncertainty Sources in Climate Change Projections

Uncertainty in climate change projections arises at each of the steps involved in their preparation: determination of greenhouse gas and aerosol emissions, concentrations of radiatively active species, radiative forcing, and climate response including downscaling. At each step, uncertainty in the estimation of the true "signal" of climate change is introduced by both errors in the model representation of Earth system processes and by internal climate variability. Despite this, there is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above (Randall et al., 2007).

The AR4 concluded (Randall et al., 2007) that one source of confidence in climate models comes from the fact that AOGCMs are based on established physical laws, while a second source of confidence comes from their ability to simulate important aspects of the current climate. Current global model ability to represent many important features of observed climate variability increases confidence that they simulate the essential physical processes relevant for the simulation of future climate change. However, the skill of global and regional climate models in representing key processes depends on the underlying processes themselves – particularly those involving feedbacks, and this is especially the case for climate extremes and associated impacts. Some processes are still poorly represented and/or understood despite major improvements in the simulations of others (see Box 3.3. and below).

A third source of confidence comes from the ability of models to reproduce features of past climates and climate changes. The AR4 demonstrated that global statistics of extreme events for present day climate are surprisingly well simulated by current AOGCMs considering their resolution and large-scale systematic errors (Randall et al., 2007). However, the assessment of climate model performance with respect to extremes, particularly at the regional or local scale, is still limited by the fact that the very rarity of extreme events makes statistical evaluation of model performance less robust than is the case for average climate. Also, evaluation is still hampered by incomplete data on the historical frequency and severity of extremes, particularly for variables other than temperature and precipitation (Trenberth et al., 2007) .

Most shortcomings in AOGCMs and in many RCMs result from the fact that many important small-scale processes (e.g., representations of clouds, convection, land-surface processes) are not represented explicitly (Randall et al., 2007). Limitations in computing power and in the scientific understanding of some physical processes, including the complexity of the feedbacks involved (Section 3.1.5), currently restrict further global and regional model improvements. These problems limit quantitative assessments of the magnitude and timing, as well as regional details, of some aspects of projected climate change. For instance, even atmospheric models at approximately 20 km horizontal resolution are still not resolved sufficiently finely to simulate the high wind speeds and low pressure centres of the most intense hurricanes (Gutowski et al., 2008a). Realistically capturing details of such intense hurricanes, such as the inner eyewall structure, would require models with 1 km horizontal resolution, far beyond the capabilities of current AOGCMs and of most current RCMs. Extremes may also be impacted by mesoscale circulations that AOGCMs and even current RCMs cannot resolve, such as low-level jets and their coupling with intense precipitation (Anderson et al., 2003; Menendez et al., 2010). Another issue with small-scale processes is the lack of relevant observations, such as is the case e.g., with soil moisture and vegetation processes (Section 3.2.1.) and associated parameters (e.g., maps of soil types, c.f. Seneviratne et al., 2006b; Anders and Rockel, 2009).

Since many extreme events occur at rather small temporal and spatial scales, where climate simulation skill is currently limited and local conditions are highly variable, projections of future changes cannot always be made with a high level of confidence (Easterling et al., 2008). The credibility in projections of changes in extremes varies with extreme type, season, and geographical region (Box 3.3). Confidence and credibility in projected changes in extremes increase when the physical mechanisms producing extremes in models are considered reliable (Kendon et al., 2009). The ability of a model to capture the full distribution of variables – not just the mean – together with long-term trends in extremes, implies that some of the processes relevant to a future warming world may be captured (van Oldenborgh et al., 2005; Alexander and Arblaster, 2009). It should, however, be noted that detection of trends is a signal-to-noise problem and that the noise is greater at regional and smaller scales so perhaps models should not be expected to simulate such trends well (Alexander and Arblaster, 2009). It should also be stressed that physical consistency of simulations with observed behaviour provides only necessary and not sufficient evidence for credible projections (Gutowski et al., 2008a). Knowledge on the sufficient conditions for accurate projections is limited by the fact that we do not yet know how to properly evaluate climate models for the sake of increasing credibility of projections (Glecker et al., 2008).

While downscaling techniques can improve the AOGCM information at fine scales by accounting for the effects of regional forcing, they are all still affected by systematic errors in the driving AOGCMs. Uncertainty due to structural or parameter errors in AOGCMs propagates directly from global model simulations as input to downscaling models and thus to downscaled information. Additionally, forcing factors such as land-use changes at local scales are not generally incorporated in either dynamical or statistical downscaling. Moreover, most downscaling approaches do not allow for the diagnosed fine-scale processes to feedback onto the larger scales – exceptions are approaches such as two-way nesting of RCMs (e.g., Lorenz and Jacob, 2005) or variable-resolution AOGCMS (e.g., Déqué et al., 1998). In many cases, regional downscaling has been rather ad-hoc and driven by specific and localised applications; this is especially true for statistical downscaling. As a result, there has been rather little coordinated evaluation or application of various downscaling techniques. Although some examples of intercomparisons are noted above, these are not complete end-to-end assessments fully exploring the effects of downscaling on the projected impacts, including impacts modelling uncertainty. In general, downscaled information has been rather underused in impact and adaptation assessments (Giorgi et al., 2009; Wilby et al., 2009). For example, much of the regional climate change material assessed in the AR4 WGI report was based on relatively coarse resolution AOGCM simulations (e.g., Christensen et al., 2007), although the growing use of higher resolution, downscaled scenarios for impacts assessment was acknowledged by WGII (Carter et al., 2007).

3.2.3.3. Ways of Exploring and Quantifying Uncertainties

Uncertainties can be explored, and quantified to some extent, through a combined use of observations, process understanding, a hierarchy of climate models, and ensemble simulations. Ensembles of model simulations represent a fundamental resource for studying the possible range of plausible climate responses to a given forcing (Meehl et al., 2007b; Randall et al., 2007). Such ensembles can be generated either by collecting results from a range of models from different modelling centres (multi-model ensembles) or by generating simulations with different initial conditions (intra-model ensembles) or varying multiple internal model parameters within plausible ranges (perturbed and stochastic physics ensembles).

Many of the global models utilized for the AR4 were integrated as ensembles, permitting more robust statistical analysis than is possible if a model is only integrated to produce a single projection. Thus the AR4 AOGCM simulations reflect both inter- and intra-model variability. In advance of AR4, coordinated climate change experiments were undertaken which provided information from 23 models from around the world (Meehl et al., 2007a). The simulations (referred to henceforth as the AR4 MME - multi-model ensemble) were made available in a central archive. However, the higher temporal resolution (i.e., daily) data necessary to analyze most extreme events were quite incomplete in the archive, with only four models providing daily averaged output with ensemble sizes greater than three realizations and many models not included at all.

It is important to distinguish between the uncertainty due to lack of agreement in the model projections (termed *insufficient congruence* in Tables 3.1-3.3), the uncertainty due to *insufficient evidence* (insufficient observational data to constrain the model projections or insufficient number of simulations to infer projections), and the uncertainty induced by *insufficient literature*, which refers to the lack of published analyses of projections (the terms in italic referring to assessments provided in Tables 3.1-3.3). For instance, models may agree on a projected change, but if this change is controlled by processes that are not well understood and validated in the present climate, then there is an inherent uncertainty in the projections, no matter how good the model agreement may be. Similarly, available model projections may agree in a given change, but the number of available simulations may restrain the reliability of the inferred agreement (e.g., because the analyses need to be based on daily data which may not be available from all modelling groups). *Insufficient congruence* of model projections, may itself be induced by different factors, most importantly the uncertainty in the initialization of climate projections, the uncertainty in emission scenarios, and the inter-model uncertainty (e.g., Hawkins and Sutton, 2009). Hawkins and Sutton (2009) examined how the influence of these three important sources of uncertainty impact the overall uncertainty of regional climate predictions of *mean temperature* changes as the forecast lead-time increases, based on global climate simulations. At short lead-times (a decade or so) natural internal variability is very important because good projections of some aspects of the internal variability (e.g., the El Niño – Southern Oscillation) rely on good initialisations of models and this may not be possible in current climate change models. At longer lead-times (50-100 years) uncertainty in future emissions of greenhouse gases (“scenario uncertainty”) becomes the dominant source of uncertainty for projections of mean temperature, even on a regional scale. Inter-model uncertainty (e.g., differences between the ways models treat important aspects of the climate system such as clouds and land surface processes) is important at all lead-times for mean temperature, although it is overwhelmed by scenario uncertainty at long lead-times. Whereas the results discussed above are for mean temperature, a similar analysis for mean precipitation reveals somewhat different results regarding the impact of inter-model uncertainty, which is found to dominate the overall uncertainty at all lead times (Hawkins and Sutton, 2010). This is consistent with the analysis of e.g., Tebaldi et al., (2006), where inter-model uncertainty was found to still overlap or even be larger than scenario uncertainty for certain extremes (e.g., consecutive number of dry days) at long lead times. Hence, the respective impacts of model versus emission scenario uncertainty are expected to strongly depend on the considered variable and extreme (see also Box 3.3).

Uncertainty analysis of the MME in AR4 focused essentially on the seasonal mean and inter-model standard deviation values (Christensen et al., 2007; Meehl et al., 2007b; Randall et al., 2007). Where the ensemble mean projected climate change is larger than the standard deviation, the signal is generally considered to be ‘robust’. In addition, confidence was assessed in the AR4 through simple quantification of the number of models that show agreement in the sign of a specific climate change (e.g., sign of the change in frequency of extremes) – assuming that the greater the number of models in agreement, the greater the robustness. However, since the ensemble was strictly an “ensemble of opportunity”, without sampling protocol, the spread of models did not span the full possible range of uncertainty. Also, the possible dependence of different models on one another (e.g., due to shared parameterizations) was not assessed.

Furthermore, this particular metric, that assesses sign agreement only can provide misleading conclusions in cases, for example, where the projected changes are near zero.

Post-AR4 studies have concentrated more on the use of the MME in order to better characterize uncertainty in climate change projections, including those of extremes (Kharin et al., 2007; Gutowski et al., 2008a; Perkins et al., 2009), and new techniques have been developed for exploiting the full ensemble information, in some cases using observational constraints to construct PDFs (Tebaldi and Knutti, 2007; Tebaldi and Sanso, 2009). Perturbed-physics ensembles have also become available (e.g., Collins et al., 2006; Murphy et al., 2007), and subsequently, advances had been made in developing probabilistic information at regional scales from the AOGCM simulations, although these methods still remain in the exploratory phase and focused on variables such as mean temperature. There has been less development extending this to downscaled regional information and to extremes (Fowler et al., 2007b; Fowler and Ekstrom, 2009) although downscaling methods are maturing and being more widely applied (despite being still restricted in terms of geographical coverage).

Both statistical and dynamical downscaling methods are affected by the uncertainties which affect the global models. A further level of uncertainty associated with the downscaling step also needs to be taken into consideration. The extent to which particular GCM and RCM biases may interact with each other or cancel out (Laprise et al., 2008) has not been extensively studied – although, for example, Kjellström and Lind (2009) conclude that the wet bias over the Baltic Sea in their chosen driving GCM is reinforced by the particular RCM used. As well as structural differences in RCMs, the choice of regional domain may introduce uncertainty, and the choice of large-scale predictors is one source of uncertainty in statistical downscaling. While downscaling provides more spatial detail, the added value of this step needs to be assessed (Laprise et al., 2008). One test of this is whether or not the downscaled outputs agree better with observations than the GCM outputs for the same variable. However this is only one test of model credibility – an over-fitted statistical model, for example, may not be credible for future projections. Spatial inhomogeneity of both land-use and land-cover change, and aerosol forcing, add to regional uncertainty. This means that the factors inducing uncertainty in the projections of extremes in different regions may differ considerably.

The increasing availability of co-ordinated RCM simulations for different regions permits more systematic exploration of downscaling uncertainty. Such simulations are available for Europe (e.g., Christensen and Christensen, 2007; van der Linden and Mitchell, 2009) and a few other regions such as North America (Mearns et al., 2009) and west Africa (van der Linden and Mitchell, 2009; Hourdin et al., 2010). RCM intercomparisons have also been undertaken for a number of regions including Asia (Fu et al., 2005), South America (Menendez et al., 2010) and the Arctic (Inoue et al., 2006). A new series of co-ordinated simulations covering the globe is planned (Giorgi et al., 2009). Increasingly, RCM output from these co-ordinated simulations is made available at the daily timescale, facilitating the analysis of extreme events.

Attempts have been made to quantify the relative importance of the different sources of uncertainty in downscaled simulations – focusing largely on mean temperature and precipitation rather than extremes. Based on an analysis of a large European RCM ensemble, Déqué et al., (2007) concluded that for the end of the 21st century, the uncertainty in mean changes related to the choice of driving GCM is generally larger than that due to choice of RCM or emissions scenario and natural variability. However, the choice of RCM was found to be as important as choice of GCM for summer precipitation – a finding confirmed by other studies (e.g., de Elía et al., 2008). Ensuring adequate sampling of RCMs may be more important for extremes than for changes in mean values (Frei et al., 2006; Fowler et al., 2007b). Natural variability, for example, has been shown to make a significant contribution on at least multi-annual timescales and potentially up to multidecadal timescales in the case of European projections of precipitation extremes (Kendon et al., 2008).

Many weather/climate extremes have impacts on physical systems such as soil moisture and streamflow, landslides or avalanches (after heavy rains or snow, for instance), dust storms, forest fire (after drought and heat waves), and glacier mass balance. In turn, changes in the physical environment can feedback onto the weather/climate system (Section 3.1.5). The degree to which uncertainties in these feedbacks influence the regional projections of different climate variables has not been systematically studied but is not expected to be uniform.

Roe and Baker (2007) pointed out that uncertainties in projections of future climate change have not lessened substantially in the last decades. They show that the breadth of the probability distribution, and in particular, the probability of large temperature increases, is relatively insensitive to decreases in uncertainties associated with the underlying climate processes. Since then, the sources of uncertainty have in general been more widely sampled – with most studies, for example, now using multiple models and emissions scenarios rather than relying on a single model or emissions scenario. Perturbed-physics ensembles have been extended from only considering atmospheric parameters to those involved in other model components, such as carbon cycle models (Huntingford et al., 2009) – which tends to increase the upper range of the projected mean temperature change (and hence the extremes). Much of the work on uncertainty has focused on the AOGCM scale (assisted by the availability of the AR4 MME), but more work is now possible at the regional and local scale using the emerging RCM ensembles.

3.2.3.4. Specific User Needs Regarding Climate Projections of Extremes

Alongside these scientific and technical developments in climate modelling and downscaling, there has been a growing recognition post-AR4 of the need to provide appropriate projections and related documentation and guidance for decision making, particularly with respect to adaptation (although rather little consideration has been given to risk and disaster management). It is important that the most appropriate method for constructing projections is matched to the particular application with respect to factors such as spatial and temporal resolution and complexity (Wilby et al., 2009). An essential aspect of this is the improved linkage between climate and impacts modelling – it is not always possible or recommended to use raw climate model output to directly drive impacts models. The needs of hydrological modelling (both for streamflow and soil moisture), for example, impose very specific demands, including high spatial resolution and consistency, which are not yet fully met (e.g., Koster et al., 2004a; Seneviratne et al., 2010) particularly with respect to extremes (Fowler et al., 2007a; Fowler and Wilby, 2007; Maraun et al., 2010).

User needs with respect to extreme events (see Chapters 1 and 2 and 3.1) tend to be more complex than for mean climate. Thus while the former needs are reflected in the various extremes discussed in Sections 3.3 to 3.5, there are some major gaps in what can currently be covered. In particular, there is a lack of peer-reviewed work on compound (multiple) events (Section 3.1.4 and Box 3.4), although Bayesian approaches have been used to construct joint PDFs of temperature and precipitation changes (Murphy et al., 2007; Tebaldi and Sanso, 2009). Systematic changes in the exceedances of joint extremes of temperature and precipitation quantiles (cool/dry, cool/wet, warm/dry and warm/wet modes) have been found for a number of European sites in an analysis of an RCM ensemble (Beniston, 2009). By the end of the century, the 'cool' modes are almost absent, while the 'warm' modes continue the increase observed in the 20th century: with the warm/dry mode dominating for Lugano in southern Europe and the warm/wet mode dominating for Copenhagen in northern Europe.

For some extremes and applications, sub-daily information is requested by users – for analysis of urban drainage, for example. While AOGCMS and RCMs operate at sub-daily timesteps, output is rarely archived at six-hourly or shorter temporal resolutions. Where limited studies have been undertaken of RCMs, there is evidence that at the typically used spatial resolutions they do not well represent sub-daily precipitation and the diurnal cycle of convection (Gutowski et al., 2003; Brockhaus et al., 2008; Lenderink and Van Meijgaard, 2008). The use of higher spatial resolutions sufficient to resolve convection and clouds (i.e., 1-2 km) has been suggested to give improved representation of the diurnal cycle (Hohenegger et al., 2008), although higher resolution does not necessarily guarantee improved simulation of precipitation (Hay et al., 2006). Development of sub-daily statistical downscaling methods is constrained by the availability of long observed time series for calibration and validation and this approach is not currently widely used for climate change applications.

High-spatial resolution is a common request from many users particularly with respect to precipitation – although detailed high-resolution climate change projections may not be critical nor essential for all aspects of adaptation planning (Dessai et al., 2009; Wilby et al., 2009). AOGCMs and RCMs provide area-averaged or spatially-aggregated precipitation (Osborn and Hulme, 1997; Chen and Knutson, 2008), while statistical downscaling has the potential to provide point or station-scale output. Area-averaging means that model grid boxes tend to have more days of light precipitation (Frei et al., 2003; Barring et al., 2006), and also reduces the magnitude of extremes, compared with point values. These scaling effects are expected because: (1) models sample area means; (2) observations sample points; (3) precipitation is not continuous over space; (4) therefore an extreme occurring at one location on a day does not mean that it will occur at other locations on the same days; and, (5), therefore it is expected that areal extremes will be smaller than point extremes. Haylock et al., (2008), for example, explored this 'areal reduction' or scaling issue in observed European temperature and precipitation extremes, comparing 25 km gridded values with station values. There is a clear reduction in the magnitude of all extremes higher than the annual 75th percentile of precipitation and the 90th percentile for temperature. The reduction factors also increase with return period – the median reduction for the 10-year return period is 0.66 for precipitation (exceeding 0.5 for some stations). Reductions of return period estimates have also been demonstrated at coarser aggregations for the U.S. (Chen and Knutson, 2008). These effects are relevant both to impacts studies and the inter-comparison of dynamical and statistical downscaling approaches (Schmidli et al., 2007; Timbal et al., 2008). The handling of these scaling issues may also have an effect on the magnitude of projected changes (Chen and Knutson, 2008).

While the spatial resolution of both global and regional models is increasing, the added value of this increased resolution should not be assumed and a balance may have to be made between spatial detail and robustness of the climate change signal (Hay et al., 2006) – the latter can be improved by spatial pooling and averaging (Fowler et al., 2007b; Coelho et al., 2008; Kendon et al., 2008). An issue with higher-resolution simulations is the fact that the resolved processes may still be insufficiently constrained with observational data, because observations are not available with the required spatial detail and comprehensiveness.

Different users and decision makers tend to be interested in projections over different future time periods. Information about changes at the end of the 21st century is more relevant where major infrastructure planning is involved, for example, while for many businesses including the insurance sector the next 20 or 30 years is considered long-term. For adaptation and development planning, the 2020s (i.e., 2011-2040) is considered important for climate risk information (Wilby et al., 2009). The focus in this chapter is on what the IPCC defines as 'long-term' projections out to the end of the century – as distinct from 'near-term' seasonal-to-decadal predictions. In the latter case, there is an attempt to produce an estimate of the actual evolution of the climate in the future, whereas long-term projections depend upon the underlying emissions scenario and the associated assumptions – developments that may or may not be realised. In the case of seasonal prediction prescribing initial conditions adequately is an important concern and the predictions themselves can be directly verified (Doblas-Reyes et al., 2009). The move towards fully initialized decadal prediction is very recent (Meehl et al., 2009b) – with the first co-ordinated simulations being developed in advance of AR5.

The AR4 MME provides output through the historical period (1850), to the present day and out to 2100 – giving flexibility in the periods for which projections can be constructed from global model output. Transient output is not yet so widely available from the more computationally expensive RCMs, but is available for Europe and North America, for example. At the time of AR4, RCMs were conventionally run for two snapshot periods – a present-day period (typically 1961–1990) and a scenario period (typically 2071–2100) (Christensen et al., 2007). Since then, emphasis has shifted more towards the middle of the 21st century to address requirements from stakeholders. Co-ordinated simulations for North America, for example, focus on 2041-2070 (Mearns et al., 2009), while a large ensemble of transient RCM runs for Europe for the period 1950–2050 has recently been completed, with many of the runs extending out to 2100 (van der Linden and Mitchell, 2009). While the signal-to-noise ratio of change is greatest at the end of the century, projections for the middle of the century or earlier are more relevant for many impacts applications. The balance of uncertainties is somewhat different for earlier compared with later future periods (see also Section 3.2.3.3). For some variables (mean temperature, temperature extremes), the choice of emission scenario becomes more critical than model uncertainty for the later future periods (Tebaldi et al., 2006; Hawkins and Sutton, 2009), though this does not apply for mean precipitation and some precipitation-related extremes (Tebaldi et al., 2006; Hawkins and Sutton, 2009), and has in particular not been evaluated in detail for a wide range of extremes.

3.2.3.5. Projections of Specific Extremes and their Confidence

In Sections 3.3 to 3.5, projections of the various extremes identified as being of interest in Section 3.1, are assessed. The AR4 projected changes for each of these extremes are first outlined, and then post-AR4 research is assessed to determine if any change from the AR4 assessment is justified for any of the extremes. The studies reported and assessed inevitably use a variety of different base-line and future scenario periods to calculate projected changes, together with different underlying climate model runs and emissions scenarios. Even where common data sets are used, such as the AR4 MME, different studies tend to use a different number of ensemble members. Thus care is needed in inter-comparing the magnitude of projected changes in extremes from different studies. This is not generally done here, therefore, with the focus more on the direction of change with some indication of the general magnitude of change rather than providing quantified change and ranges for all assessed studies.

The likelihood language developed for AR4 is used to describe the projected changes for each type of extreme wherever possible, i.e., "more likely than not/less likely than not", "likely/unlikely", "very likely/very unlikely" and "virtually certain/exceptionally unlikely". These terms are used both in the Sections 3.3 to 3.5 text and in the summary Tables 3.1 and 3.3. Table 3.1 provides an overview of all considered extremes (including both observed and projected changes, as well as the attribution of observed changes), while Table 3.3 focuses on projected changes in temperature and precipitation extremes. As highlighted in Section 3.2.3.3., the Tables use the term '*insufficient evidence*' where observations or the number or available projections are too limited to provide a robust assessment of projected changes, '*insufficient literature*' where there is not sufficient published literature on climate projections to make an assessment, and '*insufficient congruence*' where projections from different studies are divergent. Changes which are robust across models and studies and which are supported by an understanding of the processes are given higher confidence (see also Section 3.1.1.3). The regions included in Table 3.3 are rather fewer and in some cases sub-regions differ from those used for the observed changes in Table 3.2 since the availability of projections is generally less than for observations. Spatial scale issues and lack of literature mean that no information is provided for 'Small Islands' in either Table.

INSERT FIGURE 3.3 HERE

Figure 3.3: Regional projected changes in temperature and precipitation extremes (Americas)

INSERT FIGURE 3.4. HERE

Figure 3.4: Regional projected changes in temperature and precipitation extremes (Europe, Africa, Asia, and Oceania). See Figure 3.3. for definition of symbols.

INSERT TABLE 3.3 HERE

Table 3.3: Projected regional changes in temperature and precipitation extremes. The key for the employed abbreviations is found below the Table. Assessments for which no likelihood statements are available yet are displayed in grey in the Table (empty arrows on Figures 3.3 and 3.4).

3.3. Observed and Projected Changes of Weather and Climate

3.3.1. Temperature

Temperature is associated with several types of extremes, e.g., heat waves and cold snaps, and related impacts, e.g., on human health, ecosystems, and energy consumption (Chapter 4). Observed changes reported on in this section are based primarily on instrumental records. Temperature extremes often occur on weather timescales which require daily or higher timescale resolution data to accurately assess possible changes (Section 3.2.1). However, paleoclimatic temperature reconstructions can offer further insight to long-term changes in the occurrence of temperature extremes and their impacts. Where instrumental data is used, it is important to distinguish between mean, maximum, and minimum temperature, as well as between cold and warm extremes, due to their differing impacts. The difference between the daily maximum and minimum temperature defines the diurnal temperature range (DTR). Spell lengths (e.g., duration of heat waves) are relevant for a number of impacts.

Techniques to homogenize monthly and annual means of temperature data have a long history and have been well vetted over the past 25 years. However, homogenizing daily and even hourly temperature data has only received attention in the past decade (Section 3.2.1). Furthermore, the robustness of these methods is still an area of active research, though recent developments are showing promise. Some methods simply take adjustment factors calculated at the monthly or annual time scale and apply them to daily data (Vincent et al., 2002) while others are more sophisticated in their approach (Section 3.2.1), but there is not yet a global data set of adjusted daily temperature data as there is with monthly data. For example the changes in extreme temperature in Australia shown in Collins et al., (2000) are based on daily homogenised series of using a method which corrects series at all percentiles (Trewin and Trevitt, 1996). Della-Marta and Wanner (2006) generalized the Trewin and Trevitt (1996) method to homogenise skewness inhomogeneities and to be applicable in circumstances where overlapping daily data are not available. Della-Marta et al., (2007b) applied this method to 25 European daily temperature records which were previously unhomogenised (Wijngaard et al., 2003).

3.3.1.1. Observed Changes

The latest IPCC report (AR4) provides an extensive assessment of observed changes in temperature extremes (Trenberth et al., 2007). The following paragraphs provide a summary of the main results of this assessment. Wherever relevant, results from more recent investigations are included. We first discuss changes in mean temperatures, since changes in some temperature extremes are related to these (see also Box 3.2.). Moreover, they are also relevant for change in other extremes, such as precipitation (associated with changes in relative humidity, Section 3.3.2) or droughts (associated with changes in evaporative demand, Section 3.5.1).

Global mean surface temperatures rose by 0.74°C ± 0.18°C over the 100-year period 1906–2005. The rate of warming over the 50-year period 1956–2005 is almost double that over the last 100 years (0.13°C ± 0.03°C vs. 0.07°C ± 0.02°C per decade). Moreover, trends over land are stronger than over the oceans. For the globe as a whole, surface air temperatures over land rose at about double the ocean rate after 1979 (more than 0.27°C per decade vs. 0.13°C per decade), with the greatest warming during winter (December to February) and spring (March to May) in the Northern Hemisphere (Trenberth et al., 2007).

Regarding changes in temperature extremes on a global scale, the AR4 reports an increase in the number of warm extremes and a reduction in the number of daily cold extremes in 70 to 75% of the land regions where data are available. The most marked changes are for cold nights (below the 10th percentile threshold, based on 1961–1990), which have become rarer over the 1951 to 2003 period, whilst warm nights (above the 90th percentile threshold) have become more frequent (Trenberth et al., 2007). From 1950 to 2004, the annual trends in minimum and maximum land-surface air temperature averaged over regions with data were 0.20°C per decade and 0.14°C per decade, respectively, with a trend in diurnal temperature range (DTR) of –0.07°C per decade. For 1979 to 2004, the corresponding linear trends for the land areas where data are available were 0.29°C per decade for both maximum and minimum temperature with no trend for DTR (Vose et al., 2005).

On the regional and daily time scale, the AR4 (Trenberth et al., 2007) reports a decrease in the number of very cold days and nights and an increase in the number of extremely hot days and warm nights in most regions since the 1950s. Since 1979, daily minimum temperature has increased in most areas except western Australia and southern Argentina, and parts of the western Pacific Ocean, while daily maximum temperature also increased in most regions except northern Peru, northern Argentina, northwestern Australia, and parts of the North Pacific Ocean. In southern South America, significant increasing trends were found in the frequency of occurrence of warm nights and decreasing trends in the occurrence of cold nights, but no consistent changes in the indices based on daily maximum temperature. In Central America and northern South America, high extremes of both minimum and maximum temperature have increased.

Additional regions studied since the AR4 include central and eastern Europe (Bartholy and Pongracz, 2007; Kurbis et al., 2009), the Tibetan Plateau (You et al., 2008) and China (You et al., 2010), and North America (Peterson et al., 2008a), all of which document increases in unusually warm nights and days and a reduction in unusually cold nights and days. A study for the eastern Mediterranean also reports an increase in heat wave intensity, heat wave number and heat wave length in summer (Kuglitsch et al., 2010). A study for Uruguay (Rusticucci and Renom, 2008) suggests more complex trends in this region, with a reduction of cold nights, a positive but not significant trend in warm nights, non-significant decreases in cold days at most investigated stations, and inconsistent trends in warm days. This is consistent with reported trends in southern South America (Trenberth et al., 2007).

As reported in the AR4 (Trenberth et al., 2007), Alexander et al., (2006) and Caesar et al., (2006) have brought many regional results together, gridding the common indices or data for the period since 1951. According to Alexander et al., (2006) over 70% of the global land area sampled shows a significant decrease in the annual occurrence of cold nights; a significant increase in the annual occurrence of warm nights took place over 73% of the area. This implies a positive shift in the distribution of daily minimum temperature (Tmin) throughout the globe. Changes in the occurrence of cold and warm days show warming as well, but generally less marked. This is consistent with Tmin increasing more than maximum temperature (Tmax), leading to a reduction in DTR since 1951 in many regions. More recently, Meehl et al., (2009a) found the ratio of the number of record daily maximum temperatures to record daily minimum temperatures averaged across the USA is now about 2 to 1, whereas in the 1960s the ratio was approximately 1 to 1. However, some regions experienced an increase in DTR at least in some seasons: for instance, over the 1979-2005 time period, a DTR increase was reported in Europe for the spring and summer seasons, while DTR generally decreased in autumn and winter (Klok and Klein Tank, 2009). Recently, Makowski et al., (2009) have shown that trends in DTR in Europe appear to follow closely trends in surface solar radiation (induced by changes in aerosols and cloud cover), (Wild, 2009), and display a decreasing trend over the so-called “dimming period” and positive trend over the “brightening period” in summer and autumn. Links between trends in surface solar radiation and DTR may also be enhanced by soil moisture feedbacks (Jaeger and Seneviratne, 2010).

At the time of the AR4 (Trenberth et al., 2007), only a few studies had examined changes in both the high and low tail of the same daily (minimum, maximum or mean) temperature distribution. Results suggest that these do not warm uniformly in several regions (e.g., Alexander et al., 2006). For instance, Klein Tank and Können (2003) analysed such changes over Europe using standard indices, and found that the annual number of warm extremes (days above the 90th percentile for 1961 to 1990) of the daily minimum and maximum temperature distributions increased twice as fast during the last 25 years than expected from the corresponding decrease in the number of cold extremes (days below the 10th percentile). Brunet et al., (2006) examined Spanish stations for the period 1894 to 2003 and found greater reductions in the number of cold days than increases in hot days. Since 1973, however, warm days have been rising dramatically, particularly near the Mediterranean coast. On the other hand, Griffith et al (2005) report consistent trends in the low and high tails of the temperature distributions and no significant changes in standard deviation for stations in the Asia-Pacific region in the 1961-2003 period, with the exception of urbanized locations (see also Box 3.2).

INSERT FIGURE 3.5 HERE

Figure 3.5: Annual PDFs for temperature indices for 202 global stations with at least 80% complete data between 1901-2003 for three time periods: 1901-1950 (black), 1951-1978 (blue), and 1979-2003 (red). The x-axis represents the percentage of time during the year when the indicators were below the 10th percentile for cold nights (left) and above the 90th percentile for warm nights (right). From Alexander et al., (2006).

Using the recently homogenized time series noted above, Della-Marta et al., (2007a) found that previous estimates of European summer temperature increases in mean and extreme temperatures over the period 1880-2005 are conservative (Klein Tank et al., 2002). Mean summer maximum temperature change over the region is reported to be +1.6 ± 0.4°C whereas previous estimates were around +1.3 ± 0.2°C. Similarly the frequency of hot days has almost tripled and the maximum length heat wave, defined as maximum number of consecutive days the summer daily maximum temperature is above the 95th percentile, has doubled over the 1880-2005 period. Della-Marta et al., (2007a) also showed that European daily maximum summer temperature variability has increased since 1880 by +6 ± 2% and in central western Europe +11 ± 2%. The increase in the variability of summer temperature accounts for up to 40% of the changes in hot days showing that small changes in the variance of a PDFs lead to large increases in the response of extreme events (Katz and Brown, 1992). Modelling results suggest that observed and projected changes in variability in this region could be related to changes in soil moisture and land-atmosphere-precipitation feedbacks (Seneviratne et al., 2006a; Diffenbaugh et al., 2007; Fischer et al., 2007a; see also FAQ 3.2). Kuglitsch et al., (2009; 2010) homogenised and analysed over 250 daily maximum and minimum temperature series in the Mediterranean region since 1960. They used a variety of methods to detect and correct the daily temperature series and found that after homogenisation the positive trends in the frequency of hot days and heat waves in this area are higher than previously derived. This is due to the correction of many warm biased temperature records in the region during the 1960s and 1970s.

The record-breaking heat wave over western and central Europe in the summer of 2003 is an example of an exceptional recent extreme (Beniston, 2004; Schaer and Jendritzky, 2004). That summer (June to August) was the hottest since comparable instrumental records began around 1780 (1.4°C above the previous warmest in 1807) and evidence suggests it was the hottest since at least 1500 (Luterbacher et al., 2004). Other examples of recent extreme heat waves include the 2006 heat wave in Europe (Rebetez et al., 2008) and the 2009 heat wave in southeastern Australia. A few studies have found significant changes in heat wave occurrences. A study for the eastern Mediterranean reports an increase in heat wave intensity, heat wave number and heat wave length in summer over the 1960-2006 time period (Kuglitsch et al., 2010). Ding et al., (2009) found increasing numbers of heat waves over most of China for the 1961-2007 period and Kunkel et al., (2008) found that the USA has experienced a strong increase in heat waves since 1960, however the heat waves of the 1930s associated with the extreme drought conditions still dominate the 1895-2005 time series. Both the 2003 European heat wave (Andersen et al., 2005; Ciais et al., 2005) and the 2009 southeastern Australian heat wave were also associated with significant drought conditions. Drought conditions have been shown to be an important factor, potentially enhancing temperature anomalies during heat waves due to suppressed evaporative cooling (see also Section 3.3.1.2 and Box 3.4).

Regional paleoclimatic temperature reconstruction can help place the recent instrumentally observed temperature extremes in the context of a much longer period. For example Dobrovolny et al., (2010) reconstruct monthly and seasonal temperature over central Europe back to 1500 using a variety of temperature proxy records. They conclude that only two recent temperature extremes, the summer 2003 heatwave and the July heatwave of 2006 exceed the +2 standard error (associated with the reconstruction method) of previous monthly temperature extremes since 1500. Whereas the coldest periods within the last five centuries have occurred in the winter and spring of 1690.

In summary, regional and global analyses of temperature extremes nearly all show patterns consistent with a warming climate. Only a very few regions show changes in temperature extremes consistent with cooling, most notably the southeastern U.S. which has a documented decrease in mean annual temperatures over the 20th century (Trenberth et al., 2007). Regional observed changes in temperature extremes are detailed in Table 3.2. Research performed since the AR4 reinforces the conclusions that for the period since 1950 it is *very likely* that there has been a decrease in the number of both unusually cold days and nights, and an increase in the number of unusually warm days and nights on both a global and regional basis. Furthermore, based on a limited number of regional analyses and implicit from the documented changes in daily temperatures, it appears that warm spells, including heat waves defined in various ways, have *likely* increased in frequency since the middle of the 20th century in many regions.

3.3.1.2. Causes Behind the Changes

There is already an extensive body of literature on past and future changes in temperature extremes, and the underlying causes and mechanisms for these changes (e.g., Christensen et al., 2007; Meehl et al., 2007b; Trenberth et al., 2007). Heat waves are generally caused by quasi-stationary anticyclonic circulation anomalies or atmospheric blocking (Xoplaki et al., 2003; Meehl and Tebaldi, 2004; Cassou et al., 2005; Della-Marta et al., 2007b), and/or land-atmosphere feedbacks (Durre et al., 2000; Brabson et al., 2005; Seneviratne et al., 2006a; Diffenbaugh et al., 2007; Fischer et al., 2007a; Vautard et al., 2007), whereby the latter can act as an amplifying mechanism through impacts on evaporative cooling (e.g., Jaeger and Seneviratne, 2010) but also induce enhanced persistence due to soil moisture memory (Lorenz et al., 2010). These latter effects are mostly relevant in transitional climate regions between dry and wet climates (Koster et al., 2004b; Seneviratne et al., 2010). When considering impacts of heat waves, e.g., on human health, changes in other climate variables such as relative humidity (e.g., Diffenbaugh et al., 2007; Fischer and Schär, 2010) are also of relevance.

Compared with studies on mean temperature, studies of the attribution of extreme temperature changes are limited. Regarding possible human influences on these changes in temperature extremes, the AR4 (Hegerl et al., 2007) concludes that surface temperature extremes have *likely* been affected by anthropogenic forcing. This assessment is based on multiple lines of evidence of temperature extremes at the global scale including an increase in the number of warm extremes, and a reduction in the number of cold extremes. There is also evidence that anthropogenic forcing may have significantly increased the likelihood of regional heat waves (Alexander et al., 2006).

Post-AR4 studies tend to confirm the assessment of Hegerl et al., (2007). For example, Shiogama et al., (2006) used an optimal detection method to compare changes in daily extreme temperatures including annual maximum daily maximum and daily minimum temperatures and annual minimum daily maximum and daily minimum temperatures from observations with those simulated by a GCM at the global scale. They found evidence of anthropogenic warming in the annual warmest night, and the coldest day and night from 1950-1990 over the globe.

Detection studies of external influences on extreme temperature changes at regional scale are also very limited. Regional trends in temperature extremes could be related to regional processes and forcings that have been a challenge for climate model simulations. For example, Portmann et al., (2009) demonstrated that the rate of increase in the number of hot days per year in late spring in the southeastern U.S. over recent decades has a statistically significant inverse relationship to climatological precipitation. They speculate that changes in biogenic aerosols resulting from land use changes could be responsible. However, anthropogenic influence has been detected in temperature extremes in some regions. Meehl et al., (2007b) showed that most of the observed changes in temperature extremes for the second half of the 20th century over the U.S. are due to human activity. They compared observed changes in the number of frost days, the length of growing season, the number of warm nights, and the heat wave intensity with those simulated in a nine member multi-model ensemble simulation. The decrease of frost days, an increase in growing season length, and an increase in heat wave intensity all show similar changes over the U.S. in 20th century experiments that combine anthropogenic and natural forcings, though the relative contributions of each are unclear. Results from two global coupled climate models with separate anthropogenic and natural forcing runs indicate that the observed changes are simulated with anthropogenic forcings, but not with natural forcings (even though there are some differences in the details of the forcings).

Zwiers et al., (2010) compared observed annual temperature extremes including annual maximum daily maximum and minimum temperatures, and annual minimum daily maximum and minimum temperatures with those simulated responses to anthropogenic (ANT) forcing or anthropogenic and natural external forcings combined (ALL) by multiple GCMs. They fitted generalized extreme value (GEV) distributions to the observed extreme temperatures with a time-evolving pattern of location parameters as obtained from the model simulation, and found that both ANT and ALL influence can be detected in all the extreme temperature variables at the global scale over the land, and also regionally over many large land areas. They concluded that the influence of anthropogenic forcing has had a detectable influence on extreme temperatures that have impacts on human society and natural systems at global and regional scales. External influence is estimated to have resulted in large changes in the likelihood of extreme annual maximum and minimum daily temperatures. Globally, waiting times for events that were expected to recurred once every 20 years in the 1960s are now estimated to exceed 30 years for extreme annual minimum daily maximum temperature and 35 years for extreme annual minimum daily minimum temperature, and to have decreased to less than 10 or 15 years for annual maximum daily minimum and daily maximum temperatures respectively (Figure 3.6).

INSERT FIGURE 3.6 HERE

Figure 3.6: Estimated waiting time (years) and their 5% and 95% uncertainty limits for 1960s 20-yr return values of annual extreme daily temperatures in the 1990s climate (see text for more details). From Zwiers et al., (2010). Red, green, blue, pink error bars are for annual minimum daily minimum temperature (TNn), annual maximum daily minimum temperature (TNx), annual minimum daily maximum temperature (TXn), and annual maximum daily maximum temperature (TXx), respectively. Grey areas indicate insufficient data.

The new studies that attribute observed changes in temperature extremes at global and continental and sometimes regional scales to external forcing add support to the AR4 assessment that surface temperature extremes are *likely* affected by anthropogenic forcing.

3.3.1.3. Projected Changes and Uncertainties

Regarding projections of extreme temperatures, the AR4 (Meehl et al., 2007b) states that is *very likely* that heat waves will be more intense, more frequent and longer lasting in a future warmer climate (Figure 3.7). Cold episodes are projected to decrease significantly in a future warmer climate. Almost everywhere, daily minimum temperatures are projected to increase faster than daily maximum temperatures, leading to a decrease in diurnal temperature range. Decreases in frost days are projected to occur almost everywhere in the middle and high latitudes. Regional projected changes in temperature extremes are detailed in Table 3.3.

The AR4 (Meehl et al., 2007b) reports several studies explicitly addressing possible future changes in heat waves (using a number of different definitions), which found an increased risk of more intense, longer-lasting and more frequent heat waves in a future climate (Meehl and Tebaldi, 2004; Schär et al., 2004; Clark et al., 2006). A multi-model ensemble simulated the observed increase in heat waves over the latter part of the 20th century, and heat waves were projected to increase globally and over most regions (Tebaldi et al., 2006), although different model parameters influenced the magnitude of this projection (Clark et al., 2006). Meehl and Tebaldi (2004) showed that the pattern of future changes in heat waves, with greatest intensity increases over western Europe, the Mediterranean and the southeast and western USA, is related in part to circulation changes due to the increase in greenhouse gases. An additional factor leading to extreme heat is drier soils in a future warmer climate (Section 3.3.1.2), mostly in regions shifting from a wet to transitional climate regime (Seneviratne et al., 2006a). Schär et al., (2004), Stott et al., (2004) and Beniston (2004) used the European 2003 heat wave as an example of the types of heat waves that are likely to become more common in a future warmer climate (i.e., as a temporal analogue). There is also evidence that human influence has at least doubled the risk of the European exceptionally warm summer of 2003 and it is possible that by the 2040s, summers over southern Europe will be as warm or warmer 50% of the time (Jones et al., 2008).

A projected decrease in diurnal temperature range (DTR) in most regions in a future warmer climate was noted in the AR4 (e.g., Stone et al., 2001). The AR4 also reported on possible future cold air outbreaks. Vavrus et al., (2006) analysed seven AOGCMs run with the A1B scenario, and define a cold air outbreak as two or more consecutive days when daily temperatures are at least two standard deviations below the present-day winter mean. They found a 50 to 100% decline in the frequency of cold air outbreaks in Northern Hemisphere winter in most areas compared to the present, with the smallest reductions occurring in western North America, the North Atlantic and southern Europe and Asia, due to atmospheric circulation changes associated with the increase in greenhouse gases.

Post-AR4 studies of temperature extremes have utilised larger model ensembles (Kharin et al., 2007; Sterl et al., 2008) and generally reinforce the conclusions of AR4 as well as providing more regional detail. The U.S. Climate Change Science Program (CCSP) assessed changes in extremes over northern America. They reached the following conclusions regarding projected changes in temperature extremes (Gutowski et al., 2008a):

- Abnormally hot days and nights and heat waves are very likely to become more frequent.
- Cold days and cold nights are very likely to become much less frequent.
- Climate models indicate that currently rare extreme warm events will become more commonplace. For example, for a mid-range scenario of future greenhouse gas emissions, a day so hot that it is currently experienced only once every 20 years would occur every three years by the middle of the century over much of the continental U.S. and every five years over most of Canada. By the end of the century, it would occur every other year or more.

Analysis of the AR4 MME for Australia also indicates increases in warm nights (15–40% by the end of the 21st century) and heat wave duration, together with a decrease in the number of frost days (Alexander and Arblaster, 2009). Inland regions show greater warming compared with coastal zones (Suppiah et al., 2007; Alexander and Arblaster, 2009) and large increases in the number of days above 35°C or 40°C are indicated (Suppiah et al., 2007). A study with a single RCM projects more frequent warm nights in the entire tropical South American region and fewer cold nights (Marengo et al., 2009a).

Analyses of both global and regional model outputs show major increases in warm temperature extremes across the Mediterranean including events such as hot days (Tmax >30°C) and tropical nights (Tmax >20°C) (Giannakopoulos et al., 2009; Tolika et al., 2009). Comparison of RCM projections with data for 2007 (the hottest summer in Greece in the instrumental record with a record daily Tmax observed value of 44.8°C) indicates that the PDF for 2007 lies entirely within the PDF for 2071–2100 - thus 2007 might be considered a 'normal' summer of the future (Founda and Giannakopoulos, 2009; Tolika et al., 2009). This is consistent with earlier analyses of the 2003 European hot summer (see above). In contrast to this 'temporal analogue' approach, Beniston et al., (2007) take a 'spatial analogue' approach, concluding from an analysis of RCM output that regions such as France and Hungary, for example, may experience as many days per year above 30°C as currently experienced in Spain and Sicily. In this RCM ensemble, France is the area with the largest warming in the uppermost percentiles of daily summer temperatures although the mean warming is greatest in the Mediterranean (Fischer and Schär, 2009). New results from an RCM ensemble project increases in the amplitude, frequency and duration of health-impacting heat waves, especially in southern Europe (Fischer and Schär, 2010).

Temperature extremes were the type of extremes projected to change with most confidence in the AR4 (IPCC, 2007a). If changes in temperature extremes scale with changes in mean temperature (i.e., simple shifts of the PDF), we can infer that it is *virtually certain* that hot (cold) extremes will increase (decrease) in the coming decades (if these extremes are defined with respect to the 1960-1990 climate). Changes in the tails of the temperature distributions may not scale with changes in the mean in some regions (Box 3.2. and hereafter), though in most such reported cases hot extremes tend to increase more than mean temperature, and thus the above statement for hot extremes (*virtually certain* increase) still applies. Central and eastern Europe is a region for which it is now established that projected changes in temperature extremes result from both changes in the mean as well as by changes in the shape of the PDFs (Schär et al., 2004). The main mechanism for the widening of the distribution is linked to the drying of the soil in this region (Seneviratne et al., 2006a, see also Section 3.3.1.2). The role of land-atmosphere interactions for projected changes in temperature distribution functions, in particular through feedbacks with soil moisture or snow content, is also discussed in other studies (Brabson et al., 2005; Kharin and Zwiers, 2005; Clarke and Rendell, 2006; Jaeger and Seneviratne, 2010).

Furthermore, remote surface heating may induce circulation changes that modify the temperature distribution (Haarsma et al., 2009).

INSERT FIGURE 3.7 HERE

Figure 3.7: (a) Globally averaged changes in heat waves (defined as the longest period in the year of at least five consecutive days with maximum temperature at least 5°C higher than the 1961-1990 climatology of the same calendar day) based on multi-model simulations from nine global coupled climate models, adapted from Tebaldi et al., (2006). (b) Changes in spatial patterns of simulated heat waves between two 20-year means (2080–2099 minus 1980–1999) for the A1B scenario. Solid lines in (a) show the 10-year smoothed multi-model ensemble means; the envelope indicates the ensemble mean standard deviation. Stippling in (b) denotes areas where at least five of the nine models concur in determining that the change is statistically significant. Extreme indices are calculated only over land. Extremes indices are calculated following Frich et al., (2002). Each model's time series is centred around its 1980 to 1999 average and normalised (rescaled) by its standard deviation computed (after de-trending) over the period 1960 to 2099. The models are then aggregated into an ensemble average, both at the global and at the grid-box level. Thus, changes are given in units of standard deviations. From Meehl et al., (2007b).

Local, mesoscale and regional feedback mechanisms, in particular with land surface conditions (e.g., soil moisture, vegetation, snow) may significantly impact projections of temperature extremes at the local and regional scale, and induce uncertainties in these projections. Indeed, these processes occur on a small scale, not resolved by the models. In addition, lack of observational data (e.g., for soil moisture and snow cover, see Section 3.2.1) implies additional uncertainties induced by the lack of evidence to constrain current climate models (e.g., Roesch, 2006; Boe and Terray, 2008; Hall et al., 2008; Brown and Mote, 2009). Regarding mesoscale processes, lack of information may also affect confidence in projections. One example is changes in Mediterranean heat waves which are suggested to have the largest impact in coastal areas, due to the role of enhanced relative humidity for health impacts (Diffenbaugh et al., 2007; Fischer and Schär, 2010). But it is not clear how this pattern may or may not be moderated by sea breezes (Diffenbaugh et al., 2007).

Ganguly et al., (2009) statistically validated global warming trends across ensembles and at regional scales and found that observed heat wave intensities in the current decade are larger than worst-case projections. They also showed that model projections are relatively insensitive to initial conditions, while uncertainty bounds obtained by comparison with recent observations are wider than ensemble ranges.

In summary, climate change projections suggest a *virtual certain* increase in hot extremes and *virtual certain* decrease in cold extremes in most regions. This is mostly linked with mean changes in temperatures, although changes in temperature variability can play an important role in some regions.

3.3.2. Precipitation

Because climates are so diverse across different parts of the world, it is difficult to provide a single definition of "extreme precipitation". In general, three different methods have been used to define extreme precipitation (see also Sections 3.1.3 and 3.2.1), either based on 1) relative thresholds, i.e, percentiles, 2) absolute thresholds, or 3) return values. As an example of the first case, a daily precipitation event with an amount greater than the 95th percentile of daily precipitation for all wet days within a 30-year period can be considered as extreme. Regarding the second type of definition, a precipitation amount that exceeds predetermined thresholds above which damage may occur can also be considered as an extreme. For example, 2 inches/day of rain in the U.S., and 50mm/day or 100mm/day of rain in China have been considered as extremes. A drawback of this definition is that such an event may not occur everywhere, and the damage for the same amount of rain in different regions may be quite different depending partly on climatology. The third type of definition is common in engineering practice: engineers often use return values associated with a pre-determined level of probability for exceedance as design values, estimated from annual maximum one day or multi-day precipitation amounts over many years. Return values, similarly to relative thresholds, are defined for a given time period and region and may change over time.

The occurrence of hail associated with severe thunderstorms represents a significant hazard and can cause serious damage to automobiles, houses, and crops, and is therefore here considered separately to other extreme precipitation types. Hail occurs in most mid-latitude regions and is common in India, China, North America, and Europe. Hail damage accounts for 50% of the 20 highest insurance payouts in Australia (Hennessy et al., 2007). However, increases in public awareness and changes in reporting practices lead to inconsistencies in the record of severe thunderstorms and hail that make it difficult to detect trends in the intensity or frequency of these events (Kunkel et al., 2008).

Climate models are important tools for understanding past changes in precipitation and projecting future changes. However, for various reasons, the direct use of output from climate models is often inadequate for studies of attribution changes of precipitation in general and of precipitation extremes in particular. The most important reason is related to the fact that precipitation is often localized, with very high variability across space, and extreme precipitation events are often of very short duration. The spatial and temporal resolutions of climate models are not fine enough to well represent processes and phenomena that are relevant to precipitation, such as mesoscale atmospheric processes, topography, and land-sea distribution. Simulating extremes may be more challenging for shorter time periods because the relevant processes are likely to occur on smaller scales and thus be less well resolved. Thus, the time scale of extremes that a model can simulate well is probably tied to its spatial resolution (e.g., Gutowski et al., 2003). Some of these modelling shortcomings can be partly addressed with (dynamical and/or statistical) downscaling approaches (Section 3.2.3). In addition, in some parts of the world, precipitation extremes are poorly monitored by very sparse network systems (Section 3.2.1), resulting in high uncertainty in precipitation estimates, especially for extreme precipitation that is localized in space and of short duration, and thus limited possibilities to thoroughly validate modelling and downscaling approaches.

3.3.2.1. Observed Changes

Recent studies on past and current changes of heavy precipitation extremes in North America, some of which are included in the recent assessment of the U.S. Climate Change Science Program (CCSP) report (Kunkel et al., 2008), indicate an increasing trend over the last half century. Based on station data from Canada, the U.S., and Mexico, Peterson et al., (2008a) suggest that heavy precipitation has been increasing over 1950–2004, as well as the average amount of precipitation falling on days with precipitation. For the contiguous U.S., DeGaetano (2009) shows 20% reduction in the return period for extreme precipitation of different return levels over 1950–2007; Gleason et al., (2008) find an increasing trend in the area experiencing a much above-normal proportion of heavy daily precipitation from 1950 to 2006; Pryor et al., (2009) show evidence of increases in the intensity of events above the 95th percentile during the 20th century, with a larger magnitude of the increase at the end of the century. The largest trends towards increased annual total precipitation, number of rainy days and intense precipitation (e.g., fraction of precipitation derived from events in excess of the 90th percentile value) are focused on the central plains/northwestern Midwest (Pryor et al., 2009). In the core of the North American monsoon region in northwest Mexico, significant positive trends were found in daily precipitation intensity and seasonal contribution of daily precipitation greater than its 95th percentile in the mountain sites for the period 1961–1998. These precipitation events appear to have been derived from tropical cyclones. However, no significant changes were found in coastal stations (Cavazos et al., 2008).

Positive trends in extreme rainfall events are evident in southeastern South America, north central Argentina, northwest Peru and Ecuador (Marengo et al., 2009b; Re and Ricardo Barros, 2009). In the State of Sao Paulo, Brazil, there is evidence for an increase in magnitude and frequency of extreme precipitation events over 1950-1999 (Dufek and Ambrizzi, 2008) and 1933-2005 (Sugahara et al., 2009). Penalba and Robeldo (2010) report increases in the annual frequencies in spatially coherent areas over the La Plata Basin for both heavy and all (>0.1mm) precipitation events during summer, autumn and spring of 1950–2000. Winter is the exception, with negative trends, some of which are significant in the lower and middle Uruguay and Paraná Rivers.

A number of recent regional studies have been completed for European countries (Moberg et al., 2006; Bartholy and Pongracz, 2007; Maraun et al., 2008; Pavan et al., 2008; Zolina et al., 2008; Costa and Soares, 2009; Durão et al., 2009; Kysely, 2009; Rodda et al., 2009). According to Moberg et al., (2006), averaged over 121 European stations north of 40°N, trends in 90th, 95th and 98th percentiles of daily winter precipitation, as well as winter precipitation totals, have increased significantly over the 1901–2000 period. No overall long-term trend was observed in summer precipitation totals. For the United Kingdom (UK), Maraun et al., (2008) show widespread shifts towards greater contribution from heavier precipitation categories in winter, spring and (to a lesser extent) autumn, and towards light and moderate categories in summer during 1961–2006. Extreme rainfalls during 1961–2006 have increased up to 20% relative to the 1911–1960 period in the north-west of the UK and in parts of East Anglia, although there have also been changes in other areas, including decreases of the same magnitude over central England (Rodda et al., 2009). Zolina et al., (2008) present similar seasonally dependent changes of precipitation extremes over Germany during 1950–2004. Bartholy and Pongracz (2007) identify increases in the intensity and frequency of extreme precipitation in the Carpathian basin on an annual basis. Kysely (2009) identify spatially coherent increasing trends for heavy precipitation intensity in winter in the western region of the Czech Republic during 1961–2005. Increasing but insignificant and spatially less coherent trends in heavy precipitation prevail also in summer. Opposite trends occur in spring and the changes are spatially least coherent and insignificant in autumn. In contrast, at Emilia-Romagna, a region of northern Italy, the frequency of intense to extreme events decreases during winter, but increases during summer over the central mountains, while the number of rainy days decreases in summer during 1951–2004 (Pavan et al., 2008). In southern Portugal, spatial coherence of extreme precipitation events has increased and spatial variability decreased during 1961–2000 (Durão et al., 2009); short-term precipitation intensity tend to increase over the region, although the trend signals of the four wetness indices are insignificant at the majority of stations during the last three decades of the twentieth century (Costa and Soares, 2009).

Several recent studies have focused on Africa and, in general, have not found significant trends in extreme precipitation (Kruger, 2006; New et al., 2006; Seleshi and Camberlin, 2006; Aguilar et al., 2009). There has been no real evidence of changes in precipitation in most of south and west Africa over 1910 to 2004 (Kruger, 2006) and 1961 to 2000 (New et al., 2006). Central Africa showed a decrease in heavy precipitation over the last half century (Aguilar et al., 2009). However, data coverage for large parts of central Africa was poor. There were decreasing trends in heavy precipitation over eastern, southwestern and southern parts of Ethiopia, whereas no trends are found in the remaining part of Ethiopia over the period 1965-2002 (Seleshi and Camberlin, 2006).

Observations at 143 weather stations in ten Asia-Pacific Network countries during 1955–2007 did not indicate systematic, regional trends in the frequency and duration of extreme precipitation events (Choi et al., 2009). However, other studies have suggested significant trends in extreme precipitation at sub-regional scales in the Asia-Pacific region. Significant rising trends in extreme rainfall over the Indian region have been noted (Rajeevan et al., 2008; Krishnamurthy et al., 2009), especially during the monsoon seasons (Pattanaik and Rajeevan, 2009; Sen Roy, 2009). Zhai et al., (2005) found significant increases over the period 1951-2000 in extreme precipitation in western China, in the mid–lower reaches of the Yangtze River, and in parts of the southwest and south China coastal area, but a significant decrease in extremes is observed in north China and the Sichuan Basin. For most precipitation indices, such as heavy precipitation days and maximum one–day precipitation, You et al., (2008) observe increasing trends in the southern and northern Tibetan Plateau and decreasing trends in the central Tibetan Plateau during 1961–2005. However, the precipitation indices show insignificant increases on average. Bhutiyani et al., (2010) indicate no trend in the winter precipitation but significant decreasing trend in the monsoon precipitation in the northwestern Himalaya during 1866-2006. During the summer of 1978–2002, positive trends for heavy (25-50 mm per day) and extreme (>50mm per day) precipitation near the east coasts of east Asia and southeast Asia are observed, while negative trends are seen over southwest Asia, central China, and northeast Asia (Yao et al., 2008). Summer extreme precipitation over south China increased significantly since the early 1990s (Ning and Qian, 2009). In Peninsular Malaysia during 1971–2005 intensity of extreme precipitation increased and frequency decreased, while the trend detected for the proportion of extreme rainfall over total rainfall amount was insignificant (Zin et al., 2009). Only a few recent studies have been completed for Australia (Aryal et al., 2009). Extreme summer rainfall over the northwest of the Swan-Avon River basin in western Australia increased over 1950-2003 while extreme winter rainfall over the southwest of the basin decreased.

There have been few studies of recent trends of hailstorm frequency. Changes in hail occurrence are generally considered either directly, through analysis of actual hail measurements, or indirectly, through analysis of environmental conditions associated with hail events. The environmental conditions are typically taken from reanalysis data. Both approaches have their associated caveats; data homogeneity issues pose challenges in identifying trends in spatially and temporally rare events such as hail storms, while reanalysis data is based partly on models whose physical approximations may not be optimal for simulating conditions conducive for hail production. Kunz et al., (2009) find that hail days significantly increased during 1974-2003 in a state in southwest Germany. Cao (2008) suggests an increasing frequency of severe hail events in Ontario, Canada during 1979-2002. Xie et al., (2008) find no trend in the mean annual hail days in China from 1960 to early 1980s but a significant decreasing trend afterwards, with mostly flat or decreasing trends in mean annual hail days over their entire record length of 46 years. Brooks and Dotzek (2008) used environmental conditions derived from reanalysis data to count the frequency of favorable environments for significant severe thunderstorms in the region east of the Rocky Mountains in the U.S., and found significant variability but no clear trend in the past 50 years. Cao (2008) analyzed direct measurements of hail frequency over Ontario, Canada, and identified a robust upward trend in association with changes in atmospheric changes in convective instability and available precipitable water.

In summary, while many studies conducted since the AR4 confirm its conclusion that, despite spatial and seasonal variations in the changes of precipitation extremes, increasing trends in precipitation extremes are observed in many areas over the world (e.g., Trenberth et al., 2007), some studies have found a decreasing trend and/or no clear change in precipitation extremes over Africa (e.g., Aguilar et al., 2009) and the Asia-Pacific (Choi et al., 2009). Regional observed changes in precipitation extremes are detailed in Table 3.2 and a geographical overview is provided in Figures 3.1 and 3.2.

3.3.2.2. Causes Behind these Changes

As atmospheric moisture content increases with increases in global mean temperature, extreme precipitation is expected to increase as well and at a rate faster than changes in mean precipitation content (Allen and Ingram, 2002). In some regions, extreme precipitation is projected to increase, even if mean precipitation is projected to decrease (Christensen and Christensen, 2003; Kharin et al., 2007, see also Box 3.3). The observed change in heavy precipitation appears to be consistent with the expected response to anthropogenic forcing but a direct cause-and-effect relationship between changes in external forcing and extreme precipitation had not been established at the time of the AR4. As a result, the AR4 only concludes that it is *more likely than not* that anthropogenic influence has contributed to a global trend towards increases in the frequency of heavy precipitation events over the second half of the 20th century (Hegerl et al., 2007).

New research since the AR4 provides more evidence of anthropogenic influence on various aspects of the global hydrological cycle (Stott et al., 2010; see also Section 3.2.2.2), which is directly relevant to extreme precipitation changes. In particular, an anthropogenic influence on atmospheric moisture content is detectable (Santer et al., 2007; Willett et al., 2007; see also Section 3.2.2.2). Additionally, one observational study also suggests a strong influence of moisture on short duration extreme precipitation. Wang and Zhang (2008) show that winter season maximum daily precipitation in North America appears to be significantly influenced by atmospheric moisture content, with an increase in moisture corresponding to an increase in maximum daily precipitation. This behaviour has also been seen in model projections of extreme winter precipitation under global warming (Gutowski et al., 2008b). The thermodynamic constraint based on the Clausius-Clapeyron relation is a good predictor for extreme precipitation changes in a warmer world at regions where the nature of the ambient flows change little (Pall et al., 2007). This may support the judgment that the observed increase in extreme precipitation may, in part, be attributable to anthropogenic influence. However, the thermodynamic constraint may not be a good predictor in regions with circulation changes such as mid- to higher-latitudes where advective effects associated with changes in atmospheric circulation produce changes in mean and extreme precipitation (Meehl et al., 2005), and in the tropics (Emori and Brown, 2005) if the thermal equator shifts northward with a relatively large increase in precipitation at 0–20°N, with a concurrent decrease at 0–20°S (Pall et al., 2007). Additionally, changes of precipitation extremes with temperature also depend on changes in the moist-adiabatic temperature lapse rate, in the upward velocity, and in the temperature when precipitation extremes occur (O'Gorman and Schneider, 2009a, b; Sugiyama et al., 2010). This may be part of the reason why observations do not show increases in precipitation extremes everywhere, although a low signal to noise ratio may also play a role. However, even in regions where the Clausius-Clapeyron constraint is not closely followed, it is still appears to be a better predictor for future changes in extreme precipitation than the change in mean precipitation (Pall et al., 2007). An observational study seems also to support this thermodynamical theory. Analysis of daily precipitation from the Special Sensor Microwave Imager (SSM/I) over the tropical oceans shows a direct link between rainfall extremes and temperature: heavy rainfall events increase during warm periods (El Niño) and decreases during cold periods (Allan and Soden, 2008). However, the observed amplification of rainfall extremes is larger than that predicted by climate models (Allan and Soden, 2008), due possibly to widely varying changes in upward velocities associated with precipitation extremes (O'Gorman and Schneider, 2008). Evidence from measurements in the Netherlands also suggest that hourly precipitation extremes may in some cases increase more strongly with temperature (twice as fast) than would be assumed from the Clausius-Clapeyron relationship alone (Lenderink and Van Meijgaard, 2008).

Perfect model studies (e.g., Min et al., 2009) indicate that changes in precipitation extremes should be detectable at least on large scales. However, a quantitative comparison between model-simulated extreme precipitation and in-situ observations is more difficult because of a low signal to noise ratio and high uncertainty in both observed and model simulated extreme precipitation. There is a mismatch between spatial scales represented by area-mean extremes simulated by climate models and point estimations from station observations (Osborn and Hulme, 1997; Kharin and Zwiers, 2005). Because the number of observation stations is limited (Section 3.2.1), it is also not possible to produce reliable area estimates of daily precipitation based on station observations. The fact that most current GCMs do not simulate smaller-scale (<100 km) variations in precipitation intensity (e.g., Sections 3.1.1.2 and 3.2.3) associated with convective storms, also complicates the problem. It may still be a decade away before the influence of external forcing on daily extreme precipitation at regional scales can be detected (Fowler and Wilby, 2010). However, this conclusion may be seasonally dependent. For example, by now there is about a 50% chance of detecting anthropogenic influence on UK extreme precipitation in winter, but the likelihood of the detection in other seasons is very small (Fowler and Wilby, 2010).

Overall, new studies since AR4 have provided further evidence to support the AR4 assessment that it is *more likely than not* that anthropogenic influence has contributed to a trend towards increases in the frequency of heavy precipitation events over the 2nd half of the 20th century in many regions. However, there is still not enough evidence to make a more confident assessment regarding the causes of observed changes in extreme precipitation than that provided in the AR4 report. There is almost no literature on the attribution of changes in hail extremes, and thus no assessment can be provided for these at this point in time.

3.3.2.3. Projected Changes and Uncertainties

Regarding projected changes in extreme precipitation, the AR4 concluded that it is *very likely* that heavy precipitation events, i.e., the frequency (or proportion of total rainfall from heavy falls) of heavy precipitation, will increase over most areas of the globe in the 21st century (IPCC, 2007a) – see Figure 3.8. The tendency for an increase in heavy daily precipitation events in many regions was found to include some regions in which the mean precipitation is projected to decrease (see also Section 3.3.2.2 and Box 3.2). Post-AR4 analyses of climate model simulations generally confirm this assessment although uncertainties and model biases remain greater for precipitation than for temperature (e.g., Hawkins and Sutton, 2010, see also Section 3.2.3 and Box 3.3). More GCM and RCM ensembles have now been analysed for some regions, leading to increased robustness of the projected changes.

Kharin et al., (2007) analyzed changes in annual maxima of 24-hour precipitation in the AR4 MME. Between the time periods 2046–2065 and 1981–2000, the median MME response in extreme precipitation shows increases in the tropics and in mid- and high latitudes, and decreases in small regions in the subtropics. Decreases in extreme precipitation occur over much smaller regions compared to those for mean precipitation, and are generally not statistically significant. There are extensive subtropical areas where the models project an increase in the intensity of precipitation extremes, even though mean precipitation decreases. Except for a few small subtropical regions where the amplitude of extreme precipitation decreases, 20-year return period values for late-twentieth-century extreme precipitation events are reduced almost everywhere over the globe. Roughly speaking, the return times are reduced by a factor of two with a 10% increase in the amplitude of the 20-year return value (Figure 3.9). Return times decrease almost everywhere over landmasses, except for north Africa where they tend to increase. The greatest reductions in waiting time occur in tropical regions and high latitudes.

INSERT FIGURE 3.8 HERE

Figure 3.8: Changes in extremes based on multi-model simulations from nine global coupled climate models, adapted from Tebaldi et al., (2006). (a) Globally averaged changes in precipitation intensity (defined as the annual total precipitation divided by the number of wet days) for a low (SRES B1), middle (SRES A1B) and high (SRES A2) scenario. (b) Changes in spatial patterns of simulated precipitation intensity between two 20-year means (2080–2099 minus 1980–1999) for the A1B scenario. Solid lines in (a) are the 10-year smoothed multi-model ensemble means; the envelope indicates the ensemble mean standard deviation. Stippling in (b) denotes areas where at least five of the nine models concur in determining that the change is statistically significant. Extreme indices are calculated only over land following Frich et al., (2002). Each model's time series was centred on its 1980 to 1999 average and normalised (rescaled) by its standard deviation computed (after de-trending) over the period 1960 to 2099. The models were then aggregated into an ensemble average, both at the global and at the grid-box level. Thus, changes are given in units of standard deviations. From Meehl et al., (2007b).

INSERT FIGURE 3.9 HERE

Figure 3.9: Projected waiting times for late-twentieth-century 20-year return values of annual maximum 24-hour precipitation rates in the mid-21st century (left) and in late-21st century (right) by 14 GCMs that contributed to the IPCC AR4, under three different emission scenarios SRES B1, A1B and A2 (adapted from Kharin et al., 2007). The vertical extent of the whiskers in both directions describes the range of projected changes by all 14 climate models used in the study. The boxes indicate the central 50% of model projected changes, and the horizontal bar in the middle of the box indicates the median projection amongst the 14 models (that is, 7 models project waiting times longer than the median and 7 models project waiting times shorter than the median). Although the uncertainty range of the projected change in extreme precipitation is large, almost all models suggest that the waiting time for a late 20th century 20-year extreme 24-hour precipitation event will be reduced to substantially less than 20 years by mid-21st and much more by late-21st century, indicating an increase in frequency of the extreme precipitation at continental and sub-continental scales under all three forcing scenarios. Three global domains are: the entire globe (GLB), the global land areas (LND), the global ocean areas (OCN). Five zonal bands are: Northern Hemisphere Extratropics (NHE, 35°-90°N), Southern Hemisphere Extratropics (SHE, 35°-90°S), Tropics (TRO, 10°S-10°N), Northern subtropics (NTR, 10°-35°N), and Southern subtropics (35°-10°S). The nine continental/sub-continental land-only regions are: Africa (AFR, 20°W-60°E and 40°S-30°N), Central Asia (ASI, 45°-180°E and 30°-65°N), Australia (AUS, 105°E–180° and 45°–10°S), Europe (EUR, 20°W–45°E and 30°–65°N), North America (NAM, 165°–30°W and 25°–65°N), South America (SAM, 115°–30°W and 55°S–25°N), South Asia (SAS, 60°–160°E and 10°S–30°N), Arctic (ARC, 180° to 180° and 65°–90°N), Antarctica (ANT, 180° to 180° and 90°–65°S).

Several other post-AR4 studies use different collections of models, or different analysis techniques, or focus on different regions, but in general they confirm the findings of Kharin et al., (2007). Regional projected changes in precipitation extremes are detailed in Table 3.3 and on Figures 3.3 and 3.4. Shongwe et al., (2009a, b) analyzed change in mean and extreme precipitation in southern Africa and east Africa as simulated by twelve GCMs. Unlike Kharin et al., (2007) where every model is treated as equally credible, they assign different weights to each model according to model performance in simulating observed precipitation change. They project an increase in intensity in both heavy rainfall events and in mean precipitation rates and less severe droughts in east Africa, more severe precipitation deficits in the southwest of southern Africa and enhanced precipitation farther north in Zambia, Malawi, and northern Mozambique. Rocha et al., (2008) evaluated differences in the precipitation regime over southeastern Africa simulated by two GCMs. The intensity of all episode categories of precipitation events is increased during 2071–2100 relative to

1961–1990 practically over the whole region, whereas the number of episodes is decreased in most of the region and for most episode categories. By analyzing simulations with a single GCM, Khon et al., (2007) find a general increase in extreme precipitation for the different regions in northern Eurasia especially for winter. Su et al., (2009) find that for the Yangtze River Basin region in 2001–2050, the 50-year heavy precipitation and drought events during 1951–2000 become more frequent, with return periods falling to below 25 years. Extreme precipitation is projected to increase over Australia in 2080–2099 relative to 1980–1999 as indicated by analysis of the AR4 MME. However, there is very little model agreement between the AR4 MME that this change is significant (Alexander and Arblaster, 2009). For the Indian region, the Hadley Centre coupled model HadCM3 projects increases in the magnitude of the heaviest rainfall with CO_2 doubling (Turner and Slingo, 2009).

Future changes in extreme precipitation indices were projected with the high-resolution Meteorological Research Institute and Japan Meteorological Agency 20-km horizontal grid AGCM by Kamiguchi et al., (2006). At the end of the 21st century, heavy precipitation was projected to increase substantially in south Asia, the Amazon, and west Africa, with increased dry spell persistence in South Africa, south Australia, and the Amazon. In the Asian monsoon region, heavy precipitation was projected to increase, notably in Bangladesh and in the Yangtze River basin due to the intensified convergence of water vapor flux in summer.

High-spatial resolution is important for studies of extreme precipitation, particularly in regions of complex orography. Many post-AR4 studies have employed statistical and dynamical downscaling (Section 3.2.3) to project precipitation extremes. Wang and Zhang (2008) investigated possible changes in North American extreme precipitation probability during winter from 1949–1999 to 2050–2099, using statistical downscaling. Downscaled results suggest a strong increase in extreme precipitation over the south and central U.S. but decreases over the Canadian prairies. This spatial pattern is similar to that of the underlying GCM simulations, with more-detailed structure and much smaller amplitude over regions where the downscaling procedure has skill. These differences are perhaps due to a spatial-scale mismatch between the statistical downscaling results and those estimated using the GCM simulations. Results from the downscaling procedure represent small scales corresponding to station locations, while those from model simulations represent areas of tens of thousands of square kilometres (Section 3.2.3).

Many post-AR4 studies have employed the dynamical downscaling approach to investigate future changes in climate extremes using RCMs, sometimes combined with statistical downscaling. These RCM-based results are broadly consistent with those obtained from GCM simulations, although RCM studies generally present more detailed information (the added-value of which needs to be assessed – Section 3.2.3). Projected European precipitation extremes tend to increase in northern Europe (Frei et al., 2006; Beniston et al., 2007; Schmidli et al., 2007), especially during winter (Haugen and Iverson, 2008; May, 2008), and decrease in southern Europe (Beniston et al., 2007). Fowler and Ekström (2009) project increases in both short-duration (1-day) and longer-duration (10-day) precipitation extremes across the UK during winter, spring and autumn. In summer, model projections for the UK span the zero change line, although there is low confidence due to poor model performance in this season (see Section 3.2.3). Using daily statistics from various models Boberg et al., (2009a, b) report a clear increase in the contribution to total precipitation from more intense events together with a decrease in the number of days with light precipitation. This pattern of change was found to be robust for all European sub-regions.

In double-nested model simulations with a horizontal grid spacing of 10 km, Tomassini and Jacob (2009) find positive trends over Germany (as in the observations), although they are relatively small compared with the uncertainties except for the higher emissions A2 scenario. For the Upper Mississippi River Basin region during October–March, the intensity of extreme precipitation is projected to increase (Gutowski et al., 2008b). Simulations with a single RCM indicate an increase in the intensity of extreme precipitation events over most of southeastern South America and western Amazonia in 2071–2100, whereas in northeast Brazil and eastern Amazonia smaller or no changes are projected (Marengo et al., 2009a). Outputs from another RCM indicate an increase in the magnitude of future extreme rainfall events in the Western Port region of Australia, consistent with results based on the AR4 MME (Alexander and Arblaster, 2009), and the size of this increase is greater in 2070 than in 2030 (Abbs and Rafter, 2008). Tropical and northern Africa are projected to suffer less severe rainfall events by 2025 during most seasons except for autumn when both future land use changes and increasing greenhouse-gas concentrations are considered in the simulations (Paeth and Thamm, 2007).

Kysely and Beranova (2009) examined scenarios of change in extreme precipitation events in 24 future climate runs of 10 RCMs, focusing on a specific area of central Europe with complex orography. They show that the inter- and intra-model variability and related uncertainties in the pattern and magnitude of the change are large, although they also show that the projected trends tend to agree with those recently observed in the area, which may strengthen their credibility. Frei et al., (2006) analyzed the simulations of 6 European RCMs and they found that RCMs are capable of representing mesoscale spatial patterns in precipitation extremes, which are not resolved by current GCMs. However, large differences in summer extreme events are found when RCM formulation contributes significantly to projection uncertainty. Déqué et al., (2007) explored the uncertainty sources in seasonal precipitation projections from 10 RCM over Europe (Christensen et al., 2002). They found that the GCM-associated uncertainties are generally larger than those associated with the RCM simulations, but that the choice of the RCM is a source of uncertainty for summer precipitation projections, which can add the same uncertainty level as the choice of the GCM. However in this study, only two different AOGCMS were involved, and one of these was actually a relatively high resolution time slice (HadAM3). The conclusion by Déqué et al., (2007) is probably affected by these limitations. The downscaling of the RCMs off the time slice were going from a 100 km resolution to a 50 km resolution, which is a fairly small step. This may be one of the reasons why the RCM choice has such a small effect. Using the results from the same multimodel ensemble to assess changes to precipitation extremes over Europe by 2070–2100, Fowler et al., (2007b) found that the magnitude of change is strongly influenced by the driving GCM but moderated by the RCM, which also influences spatial pattern. May (2008) and Frei et al., (2006) described a significant overestimate in projected changes of precipitation over the Baltic Sea in models, related to unrealistic increase in summer SSTs in this area. Kendon et al., (2009) estimated the confidence in projected changes in daily precipitation across Europe using the Hadley Centre HadAM3P model. They found that 'other large scale changes' play a minor role in driving projected precipitation changes over much of Europe in winter and southern Europe in summer, at least on large spatial scales, allowing them to make confident statements about future changes.

Schmidli et al., (2007) compared 6 statistical downscaling models (SDMs) and 3 RCMs in their ability to downscale daily precipitation statistics in a region of complex topography (European Alps). In winter, over complex terrain, the better RCMs achieve significantly higher skills than the SDMs, while over flat terrain and in summer, the differences are small. Overall, downscaling does significantly contribute to the uncertainty in regional climate projections especially in summer because of stochastic processes appearing at the mesoscale and of the stronger role of local feedbacks (land surface processes, convection) during that season (Section 3.1.5). In exploring the ability of 2 SDMs in reproducing the direction of the projected changes in indices of precipitation extremes, Hundecha and Bardossy (2008) for instance, concluded that statistical downscaling seems to be more reliable during seasons when local climate is determined by large-scale circulation than by local convective processes.

The extent to which the natural variability of the climate affects our ability to project the anthropogenically forced component of changes in daily precipitation extremes was investigated by Kendon et al., (2008). They show that annual to multidecadal natural variability across Europe may contribute to significant uncertainty. Also, Kiktev et al., (2009) performed an objective comparison of climatologies and historical trends of temperature and precipitation extremes using observations and 20th century climate simulations. They do not detect significant similarity between simulated and actual patterns for the indices of precipitation extremes in most cases. Wehner et al., (2010) show that at high resolution (approximately 60 km at the equator) an AGCM can reproduce the precipitation return values of comparable magnitude as those from high-quality observations. However, at the resolutions typical of the coupled GCMs used in the IPCC AR4, the precipitation return values are severely underestimated. Also, Allan and Soden (2008) used satellite observations and model simulations to examine the response of tropical precipitation events to naturally driven changes in surface temperature and atmospheric moisture content. These observations reveal a link between rainfall extremes and temperature, with heavy rain events increasing during warm periods and decreasing during cold periods. Furthermore, the observed amplification of rainfall extremes is found to be larger than that predicted by models, suggesting that projections of future changes in rainfall extremes in response to anthropogenic global warming may be underestimated.

Confidence is still low for hail projections particularly due to a lack of hail-specific modelling studies, and a lack of agreement among the few available studies. There is little information in the AR4 regarding projected changes in hail events, and there has been little new literature since the AR4. Leslie et al., (2008) used coupled climate model simulations under the SRES A1B scenario to estimate future changes in hailstorms in the Sydney Basin, Australia. Their future climate simulations show a monotonic increase in the frequency and intensity of hailstorms out to 2050, and they suggest that the increase will emerge from the natural background variability within just a few decades. This result offers a different conclusion from the modelling study of Niall and Walsh (2005), which simulated Convective Available Potential Energy (CAPE) for southeastern Australia in an environment containing double the pre-industrial concentrations of equivalent CO_2. They found a significant projected decrease in CAPE values and concluded that "it is possible that there will be a decrease in the frequency of hail in southeastern Australia if current rates of CO_2 emission are sustained", assuming the strong relationship between hail incidence and the CAPE for 1980-2001 remains unchanged under enhanced greenhouse conditions.

3.3.3. Wind

Extreme wind speeds pose a threat to human safety, maritime and aviation activities and the integrity of infrastructure. As well, other attributes of wind can cause extreme impacts. Trends in average wind speed can influence evaporation which in turn may influence water availability and droughts (e.g., McVicar et al., 2008). Rapid transition in wind direction can affect forest fires, causing fires burning on the flank of the fire to flare up and become the new fire front (see Section 4.2.2.2, Mills, 2005). Sustained mid-latitude winds can elevate coastal sea levels (e.g., McInnes et al., 2009b) while longer term changes in prevailing wind direction can cause changes in wave climate and coastline stability (Pirazzoli and Tomasin, 2003; see also Section 3.5.4 and 3.5.5). Therefore, general changes in a range of wind parameters at the global and regional scale are of interest, but these changes are not clearly delineated within the context of extremes. For example, extreme winds in Europe are most often associated with intense winter cyclones (e.g., Knippertz et al., 2000), but these events are only indirectly related to the average atmospheric circulation (Christensen et al., 2007).

Unlike other weather and climate elements such as temperature and rainfall, extreme winds are often considered in the context of the extreme phenomena with which they are associated such as tropical and extratropical cyclones (see also Sections 3.4.4 and 3.4.5), thunderstorm downbursts and tornadoes. Changes in wind extremes may arise from changes in the intensity or location of their associated phenomena or from other changes to the climate system (e.g., a change in local convective activity). Although wind is often not used to define the extreme event itself (Peterson et al., 2008b), wind speed thresholds may be used to characterize the severity of the phenomenon (e.g., the Saffir-Simpson scale for tropical cyclones).

3.3.3.1. Observed Changes

The AR4 did not specifically address changes in extreme wind although it did report on wind changes in the context of other phenomena such as tropical and extratropical cyclones and oceanic waves. It concluded that mid-latitude westerlies have increased in both hemispheres (Trenberth et al., 2007).

Studies conducted since the AR4 are still too few to enable a comprehensive assessment of extreme wind changes. Long-term high-quality wind measurements from terrestrial anemometers are sparse in many parts of the globe due to the influence of changing instrumentation, station location, and surrounding land use (e.g., Cherry, 1988; Pryor et al., 2007; Jakob, 2010) and these issues have hampered the direct investigation of wind climatology changes. Nevertheless there have been a small number of new studies that have analysed wind speed trends from wind observations along with earlier studies for different parts of the world, some of which have also examined trends in extremes. These studies tend to point to declining trends in extremes in mid-latitudes and increasing trends in high latitudes. Several studies have compared the trends from anemometers with reanalysis products and in some cases find considerable differences (Hundecha et al., 2008) including differences in the sign of the trends (e.g., Smits et al., 2005; McVicar et al., 2008). New studies using wind proxies in the North Atlantic and Europe generally support earlier studies and indicate that there is a tendency for increased storminess around 1900 and in the 1990s, while the 1960s and 1970s were periods of low storm activity; but there are no consistent long term trends in the different available studies.

In the Northern Hemisphere, Pirazolli and Tomasin (2003) report a generally declining trend in winds from 1951 to the mid-1970s and an increasing trend since then, based on central Mediterranean records. The trends apply to both annual mean and annual maximum winds. Over the Netherlands, Smits et al., (2005) report declining trends in winds, including strong winds over 1962-2002. Significant declining trends in both summer and winter wind speeds were reported over China by Xu et al., (2006) and over the Tibetan plateau by Zhang et al., (2007b). In North America, Pryor et al., (2007) reported declining trends in wind over much of the USA over the 1973-2005 period. Lynch et al., (2004) report increasing trends in Alaska from 1921-2001. Hundecha et al., (2008) examined trends in extreme winds using non-stationary extreme value analysis over the Gulf of St Lawrence over the period 1979–2004, and found little change in wind extremes over this period.

In the Southern Hemisphere, McVicar et al., (2008) reports a statistically significant decline in wind speed over 57% of Australia over the 1975-2006 period. Positive (though not necessarily significant) trends are found over about 12% of the country including Tasmania, the interior of the mainland and coastal regions in the southeast and the far east. In Antarctica, Turner et al., (2005) reported increasing trends in mean wind speeds over the second half of the 20th century.

Some of these studies also compared anemometer-based trends to those from reanalysis products and reported differing or even opposite trends in the reanalysis data. Hundecha et al., (2008) compared anemometer trends with North American Regional Reanalysis data and found similarity in the directions of the change in the annual extremes at the selected stations but different magnitudes. Smits et al., (2005) compared in-situ trends with NCEP reanalysis over the Netherlands, and McVicar et al., (2008) with both NCEP and ERA40 over Australia, and found largely opposite trends. On the other hand, declining trends reported by Xu et al., (2006) over China were generally consistent with trends in NCEP reanalyses. Note, however, that the accuracy of trends from reanalysis data is still debated, since data assimilation can induce artificial trends in the products (e.g., Bengtsson et al., 2004).

Proxies for wind that use pressure tendencies and geostropic winds calculated from triangles of pressure observations from which storminess can be inferred have also been employed in a number of studies over Europe and the Atlantic (see 3.4.5). These studies suggest that there is a tendency for increased storminess around 1900 and in the 1990s, while the 1960s and 1970s were periods of low storm activity; but there are no long-term trends consistent between different available studies. More recent studies confirm these findings and illustrate that storminess in this region exhibits strong inter-decadal variability (Alexandersson et al., 2000; Allan et al., 2009; Wang et al., 2009b). The later half of the 20th century was punctuated by a peak in storminess around 1990 which according to Wang et al., (2009b) is unprecedented since 1874. However, no long-term trends were detected in storminess over this time period (Barring and von Storch, 2004; Barring and Fortuniak, 2009) or the period for which reanalysis data exist (Raible, 2007; Della-Marta et al., 2009).

3.3.3.2. Causes Behind the Changes

There is very little literature on the attribution of changes in winds including extremes, and so no assessment can be provided for this element at this point in time. Only one study, Wang et al., (2009c), formally detects a link between external forcing and positive trends in the high northern latitudes and negative trends in the northern midlatitudes using a proxy for wind (geostrophic wind energy) in the boreal winter.

Other studies have examined the likely causes for changes in winds including extreme winds. For example, Pirazolli and Tomasin (2003) report declining trends between 1951 and the mid-1970s and increasing trends since in the central Mediterranean. They find that the changes are positively correlated with temperature but not with the NAO index. For the British Columbian coast, Abeysirigunawardena et al., (2009) found that higher extreme winds tend to occur during the negative (i.e., cold) ENSO phase, consistent with an earlier study by Bromirski et al., (2005) who found a northward displacement of storminess in the northeast Pacific during La Niña episodes. Turner et al., (2005) note that the generally increasing trend of mean wind speeds over recent decades in Antarctica is consistent with the change in the nature of the SAM towards its high index state.

Declining wind speeds over China were reported by Xu et al., (2006) for both the winter and summer seasons. The winter declines, which result in a weakened winter monsoon circulation, were associated with greater warming over high-latitude land areas consistent with changes expected from anthropogenic warming. However the declines in summer wind speeds, resulting in a weakened summer monsoon circulation, were attributed to a cooling in central China associated with increased air pollution.

3.3.3.3. Projected Changes and Uncertainties

Projections of wind speed changes in general and wind extremes in particular were not specifically addressed in the AR4 although references are made to wind speed in relation to other variables and phenomena such as mid-latitude storm tracks, tropical cyclones and ocean waves (Christensen et al., 2007; Meehl et al., 2007b). The AR4 (IPCC, 2007a) reports that it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds associated with ongoing increases of tropical SSTs. It also reports that there is higher confidence in the projected poleward shift of the storm tracks and associated changes in wind patterns.

The small number of studies of projected extreme winds, together with shortcomings in the simulation of these events, means that it is still difficult to credibly project their future changes. Confidence in projections of wind and in particular extreme wind remains low because of the general low level of confidence in projected circulation changes in GCMs. The inability of GCMs at their present resolution to capture small scale meteorological phenomena that are often associated with extreme winds also contributes to the low confidence, although RCMs may help to address this problem as the number and regional extent of studies increases.

New studies since the AR4 provide more evidence for an increase in extreme winds in the high northern latitudes in the boreal winter and the southern ocean in the austral winter. McInnes et al., (2010) analysed global changes in average and 99th percentile wind speed (defined as the threshold dividing the highest 1% of daily winds from the remaining wind values) using daily wind speeds from nineteen models from the AR4 MMD. The top panels of Figure 3.10, reproduced from that study, show changes in average 10-m wind speeds for December to February (DJF) and June to August (JJA) for 2081-2100 relative to 1981-2000. In DJF in the Northern Hemisphere, increases in wind speed averaging 10% or more occur across northern Europe, the Arctic, northern North America and the northern Pacific between 40 and 50ºN. The wind speed increases at around 50-60ºN combined with declines to the southeast of this in the northern Pacific and Atlantic Oceans reflect the poleward movement of the storm tracks (see 3.4.5.3). Declines in wind also occur in the Mediterranean and Arabian Seas, much of Asia, and the eastern Equatorial Pacific. In JJA, consistent wind speed increases of 10% or more occur across much of the eastern U.S. through to central South America and northern and central Europe while large parts of the northeastern and equatorial Pacific undergo wind speed decrease. In the Southern Hemisphere in both seasons, a consistent strengthening of winds of over 10% occurs in the circumpolar trough between about 45 and 60ºS accompanied by a weakening of winds between about 30 and 40ºS which is associated with the poleward movement of the storm track (see 3.4.5.3). Wind speed increase also occurs in the southern Pacific Ocean between about 10 and 25°S.

INSERT FIGURE 3.10 HERE

Figure 3.10: The average of the multi-model 10 m mean wind speeds (top) and 99th percentile daily wind speeds (bottom) for the period 2080 to 2099 relative to 1980 to 1999 (% change) for December to February (left) and June to August (right) plotted only where more than 66% of the models agree on the sign of the change. Fine black stippling indicates where more than 90% of the models agree on the sign of the change and bold grey stippling (in white or light coloured areas) indicates where 66% of models agree on a small change between ±2 %. From McInnes et al., (2010).

Extreme wind speeds (bottom panels of Figure 3.10) show consistency between models over a larger portion of the globe in the direction of change, but the changes are generally less than ±5%. Increases in extremes occur in the high latitudes of both hemispheres and decreases across the lower latitudes as reported by Gasteneau and Soden (2009), but regional differences are apparent. For example, in DJF, consistent increases in extremes are seen across much of northern Europe, north Africa and west, east and southeast Asia and eastern North America. At least 90% of models agree on an increase in extreme winds of between 5 and 10% across the Arctic. In JJA, consistent increases in extremes of up to 5% occur in eastern South America, northern Australia and the south Pacific between 10 and 20 °S, and parts of Africa particularly in the northeast. Consistent increases are seen over much of the Southern Ocean, while consistent decreases are seen across large parts of the Atlantic and Indian Oceans and the northeast Pacific and northern North America.

Since the AR4 there have been several studies which have focussed on future changes to extreme winds. Gastineau and Soden (2009) used a 17-model ensemble to explore global changes in percentiles of 850 hPa wind speed. Zonally averaged changes presented in that study indicated agreement between models of a decreased frequency of the strongest wind events in the tropics and increased frequency in the strongest wind events in the extratropics.

Several regional studies have also been undertaken over Europe. Debernard and Roed (2008) reported projected statistically significant increases in 99th percentile winds across much of northern Europe, the British Isles and the ocean to the west and decreases to the south of Iceland in a variety of models under various emission scenarios (A2, B2, A1B). Increases in extreme (98th percentile) wind speeds in winter over large parts of Central Europe are also found in studies of both global and regional climate model output by Donat et al., (2009; 2010). A GCM ensemble indicates an increase of about 5% in wind speeds associated with storm events, although the changes are not statistically significant in all models.

Studies of extreme wind speed from eight RCMs have also been undertaken. Rockel and Woth (2007) reported a future increase in mean daily wind speed during winter months, and a decrease during autumn in areas influenced by North Atlantic extra-tropical cyclones. Further support for increases in extreme wind speeds over large areas of northern Europe is provided by Haugen and Iverson (2008). They report that extreme wind events become more frequent over large parts of northern Europe but note that the model responses are related to the representation of the Scandinavian pattern. Beniston et al., (2007) report that extreme wind speeds increase between 45° and 55°N, except over and south of the Alps, and become more north-westerly, but the magnitude of the increase depends on the specific RCM used. These changes were attributed to reductions in mean sea-level pressure and the generation of more North Sea storms. Given the level of agreement across models on mean and 99th percentile wind speeds illustrated in Figure 3.10, the degree to which the findings of these studies are robust across a larger set of GCMs or are a function of the particular selection of GCMs that were downscaled is not clear.

Sailor et al., (2008) statistically downscaled winds from several different climate models, to develop projections of winds over five airports in the northwest U.S. and results for 2050 suggest that summertime wind speeds may decrease by 5–10%, while changes to wintertime wind speeds were less certain.

3.4. Observed and Projected Changes in Phenomena Related to Weather and Climate Extremes

3.4.1. Monsoons

Changes in monsoon-related extreme precipitation and winds due to climate change are still not well understood, but a variety of extremes such as floods, drought or even heat waves may occur more or less frequently in the monsoon regions as a consequence of climate change. Generally, however, precipitation is the most important variable for inhabitants of monsoon regions, but it is also a variable associated with larger uncertainties in climate simulations (Wang et al., 2005; Kang and Shukla, 2006). Changes in extremes in the monsoon regions can be characterized more broadly than via precipitation only. Thus monsoon changes could be better depicted by large-scale dynamics, circulation or moisture convergence. However, few studies have focused on observed changes in the large-scale and in the regional monsoon circulations. Hence, in this section we focus on monsoon-induced changes in rainfall, but when literature is available we also provide assessments on associated circulation changes.

3.4.1.1. Observed Changes

Considering precipitation as perhaps the most important aspect of monsoon, several studies have focused on changes in this variable as an indicator of changes in monsoon induced by climate change. The delineation of the global monsoon has been mostly performed using rainfall data or outgoing longwave radiation (OLR) fields (Kim et al., 2008). The metrics based on rainfall have been used in various studies on global and regional monsoons (see IPCC, 2007a). Lau and Wu (2007) reveal two opposite time evolutions in the occurrence of rainfall events in the tropics, in overall agreement with the Climate Research Unit's (CRU) gauge-only rainfall data over land: a negative trend in moderate rain events and a positive trend in heavy and light rain events. Positive trends in intense rain located in deep convective cores of the Intertropical Convergence Zone (ITCZ), South Pacific Convergence Zone, Indian Ocean and monsoon regions. Studies based on observations for 1951-2003 (Alexander et al., 2006) suggest an increase in heavy precipitation in all the monsoon regions of the planet.

The American monsoon regions are vulnerable to climate change and especially to extreme climate events such as intense droughts and floods (e.g., Cavazos et al., 2008; Kunkel et al., 2008; Marengo et al., 2009a; Marengo et al., 2009b; Soares and Marengo, 2009; Arriaga-Ramírez and Cavazos, 2010). Studies using circulation fields such as 850 hPa winds or moisture flux have been performed for the South American monsoon system for assessments of the onset and end of the monsoon (Gan et al., 2006; da Silva and de Carvalho, 2007; Raia and Cavalcanti, 2008; Nieto-Ferreira and Rickenbach, 2010). Increase in heavy precipitation during 1960-2000 in the South American monsoon have been documented by Marengo et al., (2009a; 2009b), and Rusticucci et al., (2009). For the North American monsoon region, Cavazos et al., (2008) find increases in the intensity of precipitation in the mountain sites of northwestern Mexico over the 1961-1998 period, which appear to be related to an increased contribution from heavy precipitation derived from tropical cyclones (TCs). The authors also find that TC-related extreme precipitation events are associated with SST anomalies similar to weak La Niña conditions in the eastern Equatorial Pacific and a strong land-sea thermal contrast over northwest Mexico and the U.S. southwest two weeks prior to their onset. Arriaga-Ramirez and Cavazos (2010) find that total and extreme rainfall in the monsoon region of western Mexico and the U.S. southwest have significantly increased during 1961–1998, mainly by an important contribution from the winter season. Groisman and Knight (2008) find that consecutive dry days with periods longer than one month, have significantly increased in the U.S. southwest.

Zhou et al., (2008b) focused on large- or regional-scale dynamic fluctuations rather than on the regional-scale precipitation variations for the southeast Asian-Australian monsoon. In the Indo Pacific region, covering the southeast Asian and north Australian monsoon, Caesar et al., (2010) identify less spatial coherence in trends in precipitation extremes across the region between 1971 and 2003. In the few cases where statistically significant trends in precipitation extremes have been identified, there is generally a trend towards wetter conditions in common with the global results of Alexander et al., (2006). Some of the extreme precipitation appears to be positively correlated with a La Niña-like SST pattern. Guo et al., (2010) analyze near-surface wind speed change in China and its monsoon regions from 1969 to 2005 and show a significant weakening in annual and seasonal mean wind. These changes indicate reduced fluctuations in wind and wind storms in recent decades, contributing to decreased frequency and magnitude of dust storms (though an increase has been reported in more recent years, see also Section 3.5.8). The trivial changes in summer winds in east and southeast China suggest fairly steady monsoon winds over the decades. A main cause of the weakening wind is shown to be the weakening in the lower-tropospheric pressure-gradient force, a result pointing to climate variation as the primary source of the wind speed change. Superimposed on the climate effect is the urban effect. Liu et al., (2010) shows a decline in recorded precipitation events over in China 1960–2000, which is mainly accounted for by the decrease of light precipitation events, with intensities of 0.1–0.3 mm/day.

For the Indian monsoon, Rajeevan et al., (2008) showed that extreme rain events have an increasing trend between 1901 and 2005, but the trend is much stronger after 1950. Previously, Goswami et al., (2006) found that for 1950-2003, both the frequency of occurrence and intensity of extreme rain events over central India exhibited a significant increasing trend, while that of the weak and moderate rain events showed a significant decreasing trend. Sen Roy (2009) investigated changes in extreme hourly rainfall in India, and found widespread increases in extreme heavy precipitation events across India, mostly in the high-elevation regions of the northwestern Himalaya as well as along the foothills of the Himalaya extending south into the Indo-Ganges basin, and particularly during the summer monsoon season during 1980-2002. Goswami et al., (2006) explain the higher intensity of extreme rain events over central India have reflected a significant decreasing trend in light precipitation, which has also being detected in China (Liu et al., 2010).

In the African monsoon region, Fontaine et al., (2010) investigated recent observed trends using high-resolution gridded precipitation from the Climatic Research Unit (period 1979–2002), OLR and the NCEP reanalyses. The results show a rainfall increase in north Africa since the mid-90s with significant northward migrations of rainfall amounts, i.e., +1.5°C for the 400 mm July to September isohyets, whereas deep convection has significantly increased and shifted northward. After 1993–1994, the migration of the Saharan heat low towards northwest has been more marked.

The AR4 (Hegerl et al., 2007) concluded that the current understanding of climate change in the monsoon regions remains one of considerable uncertainty with respect to circulation and precipitation. With few exceptions in some monsoon regions, this has not changed since.

3.4.1.2. Causes Behind the Changes

The observed negative trend in global land monsoon rainfall is better reproduced by atmospheric models forced by observed historical SST, than by coupled models without explicit forcing by observed ocean temperatures (Kim et al., 2008). The trend is strongly linked to the warming trend over the central eastern Pacific and the western tropical Indian Ocean (Zhou et al., 2008b). The decrease in global land monsoon rainfall mainly occurred in the north African and south Asian monsoons. The long-term changes of the other monsoon subsystems are not significant in the context of regional averages (Zhou et al., 2008a). For the west African monsoon, Joly and Voldore (2009) explore the role of Gulf of Guinea SSTs in its interannual variability. In most of the studied CMIP3 simulations, the inter-annual variability of SST is very weak in the Gulf of Guinea, especially along the Guinean Coast. As a consequence, the influence on the monsoon rainfall over the African continent is poorly reproduced. It is suggested that this may be due to the counteracting effects of the Pacific and Atlantic basins over the last decades. The decreasing trend in north African monsoon rainfall may be due to the atmosphere response to observed SST variations (Hoerling et al., 2006; Zhou et al., 2008b; Scaife et al., 2009). The decrease in east Asian monsoon rainfall also seems to be related to tropical SST changes (Li et al., 2008), and the less spatially coherent positive trends in precipitation extremes in the southeast Asian and north Australian monsoons appear to be positively correlated with a La Niña-like SST pattern (Caesar et al., 2010). The link between tropical cyclones as well as the role of SST anomalies in the Eastern Equatorial Pacific, and observed increases in rainfall extremes in the North American monsoon has been investigated by Cavazos et al., (2008).

An important aspect for global monsoon patterns is the seasonal reversal of the prevailing winds. The significant weakening in annual and seasonal mean wind over China (Guo et al., 2010) indicates reduced fluctuations in wind and wind storms in recent decades, contributing to decreased frequency and magnitude of dust storms. A main cause of the weakening wind is a weakening of the lower-tropospheric pressure-gradient force. The observed changes in the African monsoon region (Fontaine et al., 2010) are associated with significant reinforcements of the southwesterly low-level winds and Tropical Easterly jet and with a northward shift of the African Easterly jet.

The CMIP3 models are able to capture the major monsoon rainfall regions around the globe, however, in regional aspects of monsoon rainfall climatology, simulations show remarkable differences depending on the horizontal resolution of the respective atmospheric models, with higher resolution models producing more realistic regional details of precipitation climatology because of better representation of surface topography. It is useful to examine changes in monsoon in a global perspective as a regional monsoon system interacts with other monsoon(s) to some extent (Meehl and Arblaster, 2002; Biasutti et al., 2003), and there is a potential improvement in the signal/noise ratio in the global monsoon system when compared with that in regional monsoons (see also Section 3.2.2 for the attribution of regional vs global changes). Observations show a negative trend in global monsoon rainfall over land during 1948–2003, primarily due to the weakening of the summer monsoon rainfall in the Northern Hemisphere (Wang and Ding, 2006). A similar trend in global monsoon precipitation in land regions is reproduced in CMIP3 models' 20th century simulations when they include anthropogenic forcing, and for some simulations natural forcing (including volcanic forcing) as well, through the trend is much weaker in general, with the exception of one model (HadCM3) capable of producing a trend of similar magnitude (Li et al., 2008). The trend in the Northern Hemisphere monsoons detected in the CMIP3 models is generally consistent with the observations, albeit with much weaker magnitude (Kim et al., 2008). The global oceanic monsoon precipitation has increased since 1980, and this positive trend is reproduced by 20 of the 21 CMIP3 models, though the models that do not include natural forcing (with MRI CGCM2.3.2a an exception) produce a more significant positive trend. The model resolution does not exhibit a considerable influence on trend simulation (Kim et al., 2008).

In summary, the CMIP3 models are able to simulate the global monsoon characteristics reasonably well. However, models do not agree in the sign of the trend of large-scale changes in the monsoon circulation, and models of finer resolution do not provide better representations of tropical monsoon circulation trend (Kim et al., 2008). As well, models with finer resolution do not show a significant east Asian summer monsoon response to external forcing (Kripalani et al., 2007a). AGCM studies suggest that several dynamic monsoon indices representing Asian-Australian monsoon circulation are forced primarily by tropical SST changes (Zhou et al., 2009) in association with El Niño activity.

Changes in regional monsoons are strongly influenced by the changes in the states of dominant patterns of climate variability such as the El Niño – Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the Northern Annular Mode (NAM), the Atlantic Multi-decadal Oscillation (AMO), and the Southern Annular Mode (SAM) (see also Sections 3.4.2 and 3.4.3). However, it is not always clear how those modes may have changed in response to external forcing (Shiogama et al., 2005). Additionally, model-based evidence has suggested that land surface processes and land use changes could in some instances significantly impact regional monsoon. Tropical land cover change in Africa and southeast Asia appears to have weaker local climatic impacts than Amazonia does, in large part due to influences of the Asian and African monsoon circulation systems in those regions (Voldoire and Royer, 2004; Mabuchi et al., 2005a, b). Grimm et al., (2007) suggest that in the South American monsoon region, precipitation anomalies, remotely forced in the spring, produce soil moisture and near surface temperature anomalies, which alter the surface pressure and wind divergence. In this regard, Collini et al., (2008) explored possible feedbacks between soil moisture and precipitation during the early stages of the monsoon in South America, when the surface is not sufficiently wet, and soil moisture anomalies may thus also modulate the development of precipitation. However, the influence of historical land use on monsoon is difficult to quantify, due both to the poor documentation of land use and difficulties in simulating monsoon at fine scales. Moreover, there are still large uncertainties and a strong model dependency in the representation of the relevant land surface processes, associated parameters, and resulting interactions (Pitman et al., 2009).

3.4.1.3. Projected Changes and Uncertainties

The AR4 concluded (Christensen et al., 2007) that there "is a tendency for monsoonal circulations to result in increased precipitation due to enhanced moisture convergence, despite a tendency towards weakening of the monsoonal flows themselves. However, many aspects of tropical climatic responses remain uncertain." Post-AR4 work has not substantially changed these conclusions.

As global warming is projected to lead to faster warming over land than over the oceans (Sutton et al., 2007), the continental-scale land-sea thermal contrast, a major factor affecting monsoon circulations, may become stronger in summer and weaker in winter. Based on this hypothesis, a simple scenario is that the summer monsoon will be stronger and the winter monsoon will be weaker in the future than the present. However, model results are not as straightforward as this simple consideration (Tanaka et al., 2005), as they show a weakening of these tropical circulations by the late 21st century compared to the late 20th century. In turn, such changes in circulation may lead to changes in precipitation associated with monsoons. For instance, the monsoonal precipitation in Mexico and Central America is projected to decrease in association with increasing precipitation over the eastern equatorial Pacific through changes in the Walker Circulation and local Hadley Circulation (e.g., Lu et al., 2007). Complicating this picture further, however, is the fact that observations and models suggest that changes in monsoons are related at least in part to changes in observed SSTs (see 3.4.1.2). Changes in global SSTs are expected to be affected by anthropogenic forcing, so this may lead to changes in monsoon circulations. Furthermore, changes in rainfall depend not just upon SSTs but also upon changes in the spatial and temporal SST patterns and regional changes in atmospheric circulation.

At regional scales, there is little consensus in GCM projections regarding the sign of future change in the monsoons characteristics, mainly circulation and rainfall. For instance, while some models project an intense drying of the Sahel under a global warming scenario, others project an intensification of the rains, and some project more frequent extreme events (Cook and Vizy, 2006). Increases in precipitation are projected in the Asian monsoon (along with an increase in interannual season-averaged precipitation variability), in the Australian monsoon in southern summer, and in the southern part of the west African monsoon, but with some decreases in the Sahel in northern summer. Heavy precipitation is projected to increase in all monsoon regions by the end of the 21st century as derived from the CMIP3 model (Tebaldi et al., 2006).

Climate change scenarios for the 21st century show a weakening of the North American monsoon through a weakening and poleward expansion of the Hadley cell (Lu et al., 2007). The expansion of the Hadley cell is caused by an increase in the subtropical static stability, which pushes poleward the baroclinic instability zone and hence the outer boundary of the Hadley cell. Simple physical arguments (Held and Soden, 2006) predict a slowdown of the tropical overturning circulation under global warming. A few studies (e.g., Marengo et al., 2009a) have projected over the period 1960-2100 a weak tendency for an increase of dry spells. The projections show an increase in the frequency of rainfall extremes in southeastern South America by the end of the 21st century, possibly due to an intensification of the moisture transport from Amazonia by a more frequent/intense low-level jet east of the Andes in the A2 scenario (Marengo et al., 2009a; Soares and Marengo, 2009).

The south Asian summer monsoon could be weakened and its onset delayed due to rising temperatures in the future, according to a recent modeling study. Asfaq et al., (2009) suggest weakening of the large-scale monsoon flow and suppression of the dominant intraseasonal oscillatory modes with overall weakening of the south Asian summer monsoon by the end of the 21st century. Such changes in monsoon dynamics could have substantial impacts by decreasing summer precipitation in key areas of south Asia. In contrast, an earlier study of the AR4 MME indicates a significant increase in mean south Asian summer monsoon precipitation of 8% and a possible extension of the monsoon period, together with intensification of extreme excess and deficient monsoons (Kripalani et al., 2007b).

Kitoh and Uchiyama (2006) used 15 models under the A1B scenario to analyze the changes in intensity and duration of precipitation in the Baiu-Changma-Meiyu band at the end of the 21st century. They found a delay in early summer rain withdrawal over the region extending from Taiwan, Ryukyu Islands to the south of Japan, contrasted with an earlier withdrawal over the Yangtze Basin. They attributed this feature to El Niño-like mean state changes over the monsoon trough and subtropical anticyclone over the western Pacific region. A southwestward extension of the subtropical anticyclone over the northwestern Pacific Ocean associated with El Niño-like mean state changes and a dry air intrusion at the mid-troposphere from the Asian continent to the northwest Japan provides favorable conditions for intense precipitation in the Baiu season in Japan (Kanada et al., 2009). Kitoh et al., (2009) projected changes in precipitation characteristics during the east Asian summer rainy season, using a 5-km mesh cloud-resolving model embedded in a 20-km mesh global atmospheric model with AR4 MME mean SST changes. The frequency of heavy precipitation is projected to increase at the end of the 21st century for hourly as well as daily precipitation. Further, extreme hourly precipitation is projected to increase even in the near future (2030s) when the temperature increase is still modest. Much remains to be learned about the mechanisms that produce such inter-decadal changes in the east Asian summer monsoon, and the response of the east Asian monsoon to global warming in at least some models is not significant (Kripalani et al., 2007a).

Some of the uncertainty on global and regional climate change projections in the monsoon regions results from the model representation of resolved processes (e.g., moisture advection), the parameterizations of sub-grid-scale processes (e.g., clouds, precipitation), and model simulations of feedback mechanisms on the global and regional scale (e.g., changes in land-use/cover). Kharin and Zwiers (2007) made an intercomparison of precipitation extremes in the tropical region in all AR4 models with observed extremes expressed as 20 year return values. They found a very large disagreement in the Tropics suggesting that some physical processes associated with extreme precipitation are not well represented by the models. This reduces confidence in the projected changes in extreme precipitation over the monsoon regions.

There are substantial inter-model differences in representing Asian monsoon processes (Christensen et al., 2007). Most models simulate the general migration of seasonal tropical rain, although the observed maximum rainfall during the monsoon season along the west coast of India, the North Bay of Bengal and adjoining northeast India is poorly simulated by many models. Recently, Bollasina and Nigam (2009) show the presence of large systematic biases in coupled simulations of boreal summer precipitation, evaporation, and SST in the Indian Ocean, often exceeding 50% of the climatological values. Many of the biases are pervasive, being common to most simulations. Three-member ensembles of baseline simulations (1961–1990) from an RCM at 50 km resolution have confirmed that significant improvements in the representation of regional processes over south Asia can be achieved by models with higher spatial resolution (Kumar et al., 2006). Moreover, confirming the importance of resolution, RCMs simulate more realistic climatic characteristics over east Asia than GCMs, whether driven by re-analyses or by GCMs (Christensen et al., 2007). Subseasonal extremes of precipitation and active-break cycles of the Indian summer monsoon in climate-change projections have been analyzed by Turner and Slingo (2009). They found that the chance of reaching particular thresholds of heavy rainfall approximately doubled over northern India. The local distribution of such projections is uncertain, however, given the large spread in mean monsoon rainfall change and associated extremes amongst the GCMs. According to AR4, monsoon rainfall simulations and projections vary substantially from model to model in northern Australia, thus there is little confidence in model precipitation projections over that particular region (Christensen et al., 2007).

Many of the important climatic effects of the Madden Julian Oscillation (MJO), including its impacts on rainfall variability in the monsoons, are still poorly simulated by contemporary climate models (Christensen et al., 2007). Current GCMs still have difficulties and display a wide range of skill in simulating the subseasonal variability associated with Asian summer monsoon (Lin et al., 2008b). Most GCMs simulate westward propagation of the coupled equatorial easterly waves, but relatively poor eastward propagation of the MJO and overly weak variances for both the easterly waves and the MJO.

Most GCMs are able to reproduce the basic characteristics of the precipitation seasonal cycle associated with the South American Monsoon System (SAMS), although there are large discrepancies in the South Atlantic Convergence Zone represented by the models in both intensity and location, and in its seasonal evolution (Vera et al., 2006). In addition, models exhibit large discrepancies in the direction of the changes associated with the summer (SAMS) precipitation, which makes the projections for that tropical region highly uncertain. Lin et al., (2008a) show that the CGCMs have significant problems and display a wide range of skill in simulating the North American monsoon and associated intraseasonal variability. Most of the models reproduce the monsoon rain belt, extending from southeast to northwest, and its gradual northward shift in early summer, but overestimate the precipitation over the core monsoon region throughout the seasonal cycle and fail to reproduce the monsoon retreat in the fall.

The AR4 assessed that models fail in representing the main features of the west African monsoon although most of them do have a monsoonal climate albeit with some distortion (Christensen et al., 2007). The rainy season of the semi-arid African Sahel is projected by twenty-first simulations to start later and become shorter (Biasutti and Sobel, 2009). However, the robust agreement across models on the seasonal distribution of Sahel rainfall changes stands in contrast with large uncertainty for summertime rainfall totals there.

Other major sources of uncertainty in projections of monsoon changes are the responses and feedbacks of the climate system to emissions as represented in climate models. These uncertainties are particularly related to the representation of the conversion of the emissions into concentrations of radiatively active species (i.e., via atmospheric chemistry and carbon-cycle models) and especially those derived from aerosols product of biomass burning. The subsequent response of the physical climate system complicates the nature of future projections of monsoon precipitation. Moreover, the long-term variations of model skill in simulating monsoons and their variations represent an additional source of uncertainty for the monsoon regions, and indicate that the regional reliability of long climate model runs may depend on the time slice for which the output of the model is analyzed.

3.4.2. El Niño – Southern Oscillation

The El Niño – Southern Oscillation (ENSO) is a natural fluctuation of the global climate system caused by equatorial ocean-atmosphere interaction in the tropical Pacific Ocean (Philander, 1990). An El Niño episode is one phase of the ENSO phenomenon and is associated with abnormally warm central and east equatorial Pacific Ocean surface temperatures, while the opposite phase, a La Niña episode, is associated with cool ocean temperatures in this region. Both extremes are associated with a characteristic spatial pattern of droughts and floods. An El Niño episode is usually accompanied by drought in southeastern Asia, India, Australia, southeastern Africa, Amazonia, and northeast Brazil, with fewer than normal tropical cyclones around Australia and in the North Atlantic. Wetter than normal conditions during El Niño episodes are observed along the west coast of tropical South America, subtropical latitudes of western North America and southeastern America. Recent research (e.g., Kenyon and Hegerl, 2008; Ropelewski and Bell, 2008; Schubert et al., 2008a; Alexander et al., 2009; Grimm and Tedeschi, 2009; Zhang et al., 2010) has demonstrated that different phases of ENSO (El Niño or La Niña episodes) also are associated with different frequencies of occurrence of short-term weather extremes such as heavy rainfall events and extreme temperatures. The relationship between ENSO and interannual variations in tropical cyclone activity is well-known (e.g., Kuleshov et al., 2008). The simultaneous occurrence of a variety of climate extremes in an El Niño episode (or a La Niña episode) may provide special challenges for organizations coping with disasters induced by ENSO.

3.4.2.1. Observed Changes

The AR4 noted that the nature of the El Niño – Southern Oscillation has varied substantially over time, with strong events from the late 19th century through the first quarter of the 20th century and again after 1950. A climate shift around 1976–1977 was associated with a shift to generally above-normal SSTs in the central and eastern Pacific and a tendency towards more prolonged and stronger El Niño episodes (Trenberth et al., 2007). Paleoclimatic evidence suggested that the phenomenon was quite weak up to a few thousand years ago.

Research subsequent to the AR4 has provided evidence from fossil corals that the El Niño – Southern Oscillation has varied in strength over the last millennium with stronger activity in the 17th century and late 14th century, and weaker activity during the 12th and 15th centuries (Cobb et al., 2003; Conroy et al., 2009). On longer timescales, there is evidence that the El Niño – Southern Oscillation may have changed in response to changes in the orbit of the Earth (Vecchi and Wittenberg, 2010), with the phenomenon apparently being weaker around 6,000 years ago (according to proxy measurements from corals and climate model simulations) (Rein et al., 2005; Brown et al., 2006; Otto-Bliesner et al., 2009) and model simulations suggest that it was stronger at the Last Glacial Maximum or LGM (An et al., 2004). Fossil coral evidence does indicate that the phenomenon did continue to operate during the LGM (Tudhope et al., 2001).

Instrumental data (SST and surface atmospheric pressure measurements) allow us a more detailed study of changes in the behaviour of the phenomenon over the past century or so. Ocean temperatures in the central equatorial Pacific (the so-called NINO3 index) suggest that the phenomenon was particularly active during the 1970s and less active in the 1950s and 1960s, with perhaps a trend toward more frequent or stronger El Niño episodes over the past 50–100 years (Vecchi and Wittenberg, 2010). Vecchi et al., (2006) reported a weakening of the equatorial Pacific pressure gradient since the 1960s, with a sharp drop in the 1970s. Power and Smith (2007) proposed that the apparent dominance of El Niño during the last few decades was due in part to a change in the background state of the Southern Oscillation Index or SOI (another index of the phenomenon – the standardized difference in surface atmospheric pressure between Tahiti and Darwin), rather than a change in variability or a shift to more frequent El Niño events alone. Nicholls (2008) examined the behaviour of the SOI and another index, the NINO3.4 index of central equatorial Pacific SSTs, but found no evidence of trends in the variability or the persistence of the indices, (although Yu and Kao (2007) reported decadal variations in the persistence barrier, the tendency for weaker persistence across the Northern Hemisphere spring), nor in their seasonal patterns. There was a trend towards what might be considered more ‘‘El Niño-like’’ behaviour in the SOI (and more weakly in NINO3.4), but only through the period March–September and not in November–February, the season when El Niño and La Niña events typically peak. The trend in the SOI reflected only a trend in Darwin pressures, with no trend in Tahiti pressures. Apart from this trend, the temporal/seasonal nature of the El Niño–Southern Oscillation has been remarkably consistent through a period of strong global warming.

There is evidence, however, of a tendency for recent El Niño episodes to be centered more in the central equatorial Pacific than in the east Pacific (Yeh et al., 2009). In turn, this change in the location of the strongest SST anomalies associated with El Niño may explain changes that have been noted in the remote influences of the phenomenon on the climate over Australia and in the mid-latitudes (Wang and Hendon, 2007; Weng et al., 2009). For instance, Taschetto et al., (2009) show that episodes with the warming centred in the central Pacific exhibit different patterns of Australian rainfall variations than do other varieties of El Niño events.

3.4.2.2. Causes Behind the Changes

Regarding possible causes of changes in the El Niño – Southern Oscillation phenomenon, the AR4 concluded that "as yet there is no detectable change in ENSO variability in the observations, and no consistent picture of how it might be expected to change in response to anthropogenic forcing" (Hegerl et al., 2007). However, models did suggest that orbital variations could affect the ENSO behaviour by, for instance, reproducing an apparent increase in event frequency and amplitude throughout the Holocene (Jansen et al., 2007).

Post-AR4 studies have not changed the AR4 assessment that orbital variations could affect the ENSO activity and that there is still no clear indication of possible role of anthropogenic influence on ENSO activity. Vecchi and Wittenberg (2010) note that the "tropical Pacific could generate variations in ENSO frequency and intensity on its own (via chaotic behaviour), respond to external radiative forcings (e.g., changes in greenhouse gases, volcanic eruptions, atmospheric aerosols, etc), or both". The paleoevidence indicates that the El Niño – Southern Oscillation can continue to operate, although altered perhaps in intensity, through quite anomalous climate periods, but that it does fluctuate in response to changes in radiative forcing caused by orbital variations (Vecchi and Wittenberg, 2010). Cane (2005) noted that a relatively simple coupled model suggested that systematic changes in the El Niño could be stimulated by seasonal changes in insolation. However, a more comprehensive model simulation (Wittenberg, 2009) has suggested that long-term changes in the behaviour of the phenomenon might occur even without forcing from radiative changes.

The possible role of increased greenhouse gases in affecting the behaviour of the El Niño – Southern Oscillation over the past 50-100 years is uncertain. Some studies (e.g., Zhang et al., 2008a) have suggested that increased activity might be due to increased CO_2, however no formal attribution study has yet been completed and some other studies (e.g., Powers and Smith, 2007) suggest that changes in the phenomenon are still within the range of natural variability (ie, that no change has yet been detected, let alone attributed). Yeh et al., (2009) suggested that changes in the background temperature associated with increases in greenhouse gases should affect the behaviour of the El Niño, such as the location of the strongest SST anomalies, because El Niño behaviour is strongly related to the average ocean temperature gradients in the equatorial Pacific.

A caveat regarding all projections of future behaviour of the El Niño – Southern Oscillation arises from systematic biases in the depiction of El Niño – Southern Oscillation behaviour through the 20th century by models. Leloup et al., (2008) for instance, demonstrate that coupled climate models show wide differences in the ability to reproduce the spatial characteristics of SST variations associated with the El Niño – Southern Oscillation during the 20th century, and all models have failings. They concluded that it is difficult to even classify models by the quality of their reproductions of the behaviour of the El Niño – Southern Oscillation, because models scored unevenly in their reproduction of the different phases of the phenomenon. This makes it difficult to determine which models to use to project future changes of the El Niño – Southern Oscillation.

3.4.2.3. Projected Changes and Uncertainties

AR4 established that all models exhibited continued El Niño – Southern Oscillation (ENSO) interannual variability in projections through the 21st century, but the projected behaviour of the phenomenon differed between models, and it was concluded that "there is no consistent indication at this time of discernible changes in projected ENSO amplitude or frequency in the 21st century" (Meehl et al., 2007b).

Global warming is expected to lead to a mean reduction of the zonal winds across the equatorial Pacific (Vecchi and Soden, 2007b). This change may be described as an "El Niño – like" average change because during an El Niño episode these winds generally weaken. However, there is only limited correspondence between these changes in mean state of the equatorial Pacific and an El Niño episode. For instance, climate models project that the Indonesian region would become wetter, and this is distinctly different to a typical El Niño event.

Models project a wide variety of changes in ENSO variability and the frequency of El Niño episodes as a consequence of increased greenhouse gas concentrations, with a range between a 30% reduction to a 30% increase in variability (van Oldenborgh et al., 2005). One model study even found an increase in ENSO activity from doubling or quadrupling CO_2, but a considerable decrease in activity when CO_2 was increased by a substantial factor of 16 times (Cherchi et al., 2008).

The remote impacts, on rainfall for instance, of ENSO may also change as CO_2 increases, even if the equatorial Pacific aspect of the El Niño – Southern Oscillation does not change substantially. For instance, regions in which rainfall increases in the future tend to show increases in interannual rainfall variability (Boer, 2009), without any strong change in the interannual variability of tropical SSTs. Also, since some long-term projected changes in response to increased greenhouse gases may resemble the climate response to an El Niño event, this may enhance or mask the response to El Niño events in the future (Lau et al., 2008b; Müller and Roeckner, 2008).

One change that models tend to project is an increasing tendency for El Niño episodes to be centred in the central equatorial Pacific, rather than the traditional location in the eastern equatorial Pacific. Yeh et al., (2009) examined the relative frequency of El Niño episodes simulated in coupled climate models with projected increases in greenhouse gas concentrations. A majority of models, especially those best able to simulate the current ratio of central Pacific locations to east Pacific locations of El Niño events, projected a further increase in the relative frequency of these central Pacific events. Such a change would also have implications for the remote influence of the phenomenon on climate away from the equatorial Pacific (e.g., Australia and India).

The position at the time of the AR4 was that there was no consistency of projections of changes in ENSO variability or frequency in the future (Meehl et al., 2007b). This position has not been changed as a result of post-AR4 studies. The evidence is that the nature of the El Niño – Southern Oscillation has varied in the past apparently sometimes in response to changes in radiative forcing but also possibly due to internal climatic variability. Since radiative forcing will continue to change in the future, we can confidently expect changes in the El Niño – Southern Oscillation will as well. However, Vecchi and Wittenberg (2010) conclude "the ENSO variations we see in decades to come may be different than those we've seen in recent decades – yet we are not currently at a state to confidently project what those changes will be". However, they also observe that we are confident that El Niño and La Niña events will likely continue to occur and influence the climate but that there will continue to be variations in the phenomenon and its impacts, on a variety of timescales.

Even the projection that the 21st century may see an increased frequency of central Pacific El Niño episodes, relative to the frequency of events located further east (Yeh et al., 2009), is subject to considerable uncertainty. Of the 11 coupled climate model simulations examined by Yeh et al., (2009), three projected a relative decrease in the frequency of these central Pacific episodes, and only four of the models produced a statistically significant change to more frequent central Pacific events. As well, coupled models still have difficulty simulating the El Niño – Southern Oscillation convincingly. Moreover, most of the models are not able to reproduce the typical wavetrains observed in the circulation anomalies associated with ENSO in the Southern Hemisphere (Vera and Silvestri, 2009) and the Northern Hemisphere (Joseph and Nigam, 2006). Such model limitations somewhat undermine our confidence in the projected changes by the majority of the models. Further research is required to analyse differences between the model simulations and projections of El Niño behaviour, to determine what causes these differences.

3.4.3. Other Modes of Variability

Other natural modes of variability that are relevant to extremes and disasters include the North Atlantic Oscillation (NAO), the Southern Annular Mode (SAM) and the Indian Ocean Dipole (IOD) (Trenberth et al., 2007). The NAO is a large-scale seesaw in atmospheric pressure between the subtropical high and the polar low in the Atlantic region. The positive NAO phase has a strong subtropical high-pressure center and a deeper than normal Icelandic low. This results in a shift of winter storms crossing the Atlantic Ocean to a more northerly track, and is associated with warm and wet winters in Europe and cold and dry winters in northern Canada and Greenland. Scaife et al., (2008) discuss the relationship between the NAO and European extremes. The NAO is closely related to the Northern Annular Mode (NAM); for brevity we focus here on the NAO but much of what is said about the NAO also applies to the NAM. The SAM refers to north-south shifts in atmospheric mass between the Southern Hemisphere middle and high latitudes and is the most important pattern of climate variability in these latitudes. The SAM positive phase is linked to negative sea level pressure anomalies over the polar regions and intensified westerlies. It has been associated with cooler than normal temperatures over most of Antarctica and Australia, with warm anomalies over the Antarctic Peninsula, southern South America, and southern New Zealand. Also it has been related to anomalously dry conditions over southern South America, New Zealand, and Tasmania and with wet anomalies over much of Australia and South Africa (e.g., Hendon et al., 2007). The IOD is a coupled ocean-atmosphere phenomenon in the Indian Ocean. A positive IOD event is associated with anomalous cooling in the southeastern equatorial Indian Ocean and anomalous warming in the western equatorial Indian Ocean, and brings heavy rainfall over the east Africa and severe droughts/forest fires over the Indonesian region. There is also evidence of modes of variability operating on multi-decadal time-scales, notably the Pacific Decadal Oscillation (PDO) and the Atlantic Multi-decadal Oscillation (AMO). Variations in the PDO have been related to weather extremes (Zhang et al., 2010). As is the case with ENSO, the simultaneous occurrence of climate extremes such as droughts associated with any of these various modes of variability may have consequences for disaster management.

3.4.3.1. Observed Changes

The AR4 noted that both the NAO and the SAM have exhibited trends towards their positive phase (strengthened midlatitude westerlies) over the last three to four decades, although both have returned to near their long-term mean state in the last five years (Trenberth et al., 2007). In the Northern Hemisphere, this trend has been associated with the observed winter change in storm tracks, precipitation and temperature patterns. A paleoclimate study (Goodkin et al., 2008) reported enhanced multidecadal variability in the NAO during the late 20th century, compared with the period 1800-1850. SAM has an influence on the interannual variability of precipitation in southeastern South America (Silvestri and Vera, 2003) and New Zealand (Ummenhofer and England, 2007). The SAM influence on temperature extremes in southern South America has also been reported (Barrucand et al., 2008). The SAM trends are related to contrasting trends of strong warming in the Antarctic Peninsula and a cooling over most of interior Antarctica (e.g., Marshall et al., 2006). Complicating these trends, Silvestri and Vera (2009) reported changes in the typical hemispheric circulation pattern related to SAM and its associated impact on both temperature and precipitation anomalies, particularly over South America and Australia, between the 1960s–70s and 1980s–90s. Recent work (Ummenhofer et al., 2008; Ummenhofer et al., 2009a; Ummenhofer et al., 2009b) has implicated the IOD as a cause of droughts in Australia, and heavy rainfall in east Africa (Ummenhofer et al., 2009c). The time scales of the multi-decadal modes of variability in these modes are so long that it is difficult to diagnose any change in their behaviour in modern data.

3.4.3.2. Causes Behind the Changes

The AR4 (Hegerl et al., 2007) noted that trends over recent decades in the NAO and SAM are *likely* related in part to human activity. The increasing positive phase of the SAM has been linked to stratospheric ozone depletion and to greenhouse gas increases. Models including both greenhouse gas and stratospheric ozone changes simulate a realistic trend in the SAM. However model simulations can show positive trends in the annular modes at the surface, but negative trends higher in the atmosphere, and it has been argued that anthropogenic circulation changes are poorly characterized by trends in the annular modes (Woollings et al., 2008). Goodkin et al., (2008) conclude that the variability in the NAO is linked with changes in the mean temperature of the Northern Hemisphere.

3.4.3.3. Projected Changes and Uncertainties

The AR4 noted that there was considerable spread among the model projections of the NAO, leading to low confidence in NAO projected changes, but the magnitude of the increase for the SAM is generally more consistent across models (Meehl et al., 2007b). However, limitations in coupled model ability in reproducing the observed SAM impact on climate variability in the Southern Hemisphere has been reported (e.g., Miller et al., 2006; Vera and Silvestri, 2009). Variations in the longer time-scale modes of variability (AMO, PDO) might affect projections of changes in extremes associated with the various natural modes of variability and global temperatures (Keenlyside et al., 2008).

The AR4 noted that sea level pressure is projected to increase over the subtropics and mid-latitudes, and decrease over high latitudes (Meehl et al., 2007b). This would equate to trends in the NAO and SAM, with a poleward shift of the storm tracks of several degrees latitude and a consequent increase in cyclonic circulation patterns over the Arctic and Antarctica. During the 21st century, although stratospheric ozone concentrations are expected to stabilise or recover, tending to lead to a weakening of the SAM, polar vortex intensification is likely to continue due to the increases in greenhouse gases. A very recent study (Woolings et al., 2010) found a tendency towards a more positive NAO under anthropogenic forcing through the 21st century, although they concluded that confidence in the model projections was low because of deficiencies in its simulation of current-day NAO regimes. Goodkin et al., (2008) predict continuing high variability, on multidecadal scales, in the NAO with continued global warming. Keenlyside et al., (2008) proposed that variations associated with the multi-decadal modes of variability may offset warming due to increased greenhouse gas concentrations over the next decade or so.

3.4.4. Tropical Cyclones

Tropical cyclones occur in most tropical oceans and pose a significant threat to coastal populations and infrastructure, and marine interests such as shipping and offshore activities. Each year, about 90 tropical cyclones occur globally, and this number has been remarkably steady over the modern period of geostationary satellites (since around the mid-1970's). While the global frequency has remained steady, there can be substantial inter-annual to multi-decadal frequency variability within individual ocean basins (e.g., Webster et al., 2005). This regional variability, particularly when combined with substantial inter-annual to multi-decadal variability in tropical cyclone tracks (e.g., Kossin et al., 2010), presents a significant challenge for disaster planning and mitigation aimed at specific regions.

Tropical cyclones are perhaps most commonly associated with extreme wind, but storm-surge and fresh-water flooding from extreme rainfall generally cause the great majority of damage and loss of life. Related indirect factors, such as the failure of the levee system in New Orleans during the passage of Hurricane Katrina (2005), or mudslides during the landfall of Hurricane Mitch (1998) in Central America, are also important impacts. Projected sea level rise will further compound tropical cyclone surge impacts. Tropical cyclones that track northward can undergo a transition to become extratropical cyclones. While these storms have different characteristics than their tropical progenitors, they can still be accompanied by a storm surge that can impact northern waters well away from the tropics (e.g., Danard et al., 2004).

Tropical cyclones are typically classified in terms of their intensity, which is a measure of near-surface wind speed. While there is a relationship between intensity and storm surge, the structure and areal extent of the wind field also play an important role. Other relevant tropical cyclone measures include frequency, duration, and track. Forming robust physical links between all of these metrics and natural or human-induced climate variability is a major challenge. Significant progress is being made, but substantial uncertainties still remain due largely to data quality issues (see 3.2.1, and below) and imperfect theoretical and modeling frameworks (see below).

3.4.4.1. Observed Changes

Detection of trends in tropical cyclone metrics such as frequency, intensity, and duration remains a significant challenge. Historical tropical cyclone records, which begin in 1851 in the North Atlantic and typically in the mid-20th century in other regions, are known to be heterogeneous due to changing observing technology and reporting protocols (e.g., Landsea et al., 2004). Further heterogeneity is introduced when records from multiple ocean basins are combined to explore global trends because data quality and reporting protocols vary substantially between regions (Knapp and Kruk, 2010). Progress has been made toward a more homogeneous global record of tropical cyclone intensity using satellite data (Knapp and Kossin, 2007; Kossin et al., 2007), but these records are necessarily constrained to the satellite era and so only represent the past 30-40 years.

Natural variability combined with uncertainties in the historical data makes it difficult to detect trends in tropical cyclone activity. There have been no significant trends observed in global tropical cyclone frequency records, including over the present 40-year period of satellite observations (e.g., Webster et al., 2005). Regional trends in tropical cyclone frequency have been identified in the North Atlantic, but the fidelity of these trends is debated (Holland and Webster, 2007; Landsea, 2007; Mann et al., 2007b). Landsea et al., (2009) showed that a large contribution of the observed long-term trend in the record of North Atlantic tropical cyclone frequency is due to a trend in the frequency of short-lived storms, a subset of storms that may be particularly sensitive to changes in technology and reporting protocols. However, Emanuel (2010) demonstrates that the changes in short-duration storms may also have physical causes, and Kossin et al., (2010) find that much of the changes in the frequency of short-duration storms in the Atlantic have occurred in the Gulf of Mexico in close proximity to land and thus largely avoids the data-quality issues with pre-satellite storm undercounts.

Different methods for estimating undercounts in the earlier part of the North Atlantic tropical cyclone record provide mixed conclusions (Chang and Guo, 2007; Mann et al., 2007a; Kunkel et al., 2008; Vecchi and Knutson, 2008). Regional trends have not been detected in other oceans (Chan and Xu, 2009; Kubota and Chan, 2009). It thus remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust, after accounting for past changes in observing capabilities (Knutson et al., 2010).

Whereas frequency estimation requires only that a tropical cyclone be identified and reported at some point in its lifetime, intensity estimation requires a series of specifically targeted measurements over the entire duration of the tropical cyclone (e.g., Landsea et al., 2006). Consequently, intensity values in the historical records are especially sensitive to changing technology and improving methodology, which heightens the challenge of detecting trends within the backdrop of natural variability. Global reanalyses of tropical cyclone intensity using a homogenous satellite record have suggested that changing technology has introduced a non-stationary bias that inflates trends in measures of intensity (Kossin et al., 2007), but a significant upward trend in the intensity of the strongest tropical cyclones remains after this bias is accounted for (Elsner et al., 2008). While these analyses are suggestive of a link between observed tropical cyclone intensity and climate change, they are necessarily confined to a 30+ year period of satellite observations, and do not provide clear evidence for a longer-term trend.

Time series of power dissipation, an aggregate compound of tropical cyclone frequency, duration, and intensity that measures total energy consumption by tropical cyclones, show upward trends in the North Atlantic and weaker upward trends in the western North Pacific over the past 25 years (Emanuel, 2007), but interpretation of longer-term trends is again constrained by data quality concerns. The variability and trend of power dissipation can be related to SST and other local factors such as tropopause temperature, and vertical wind shear, but it is a present point of debate whether local SST or SST relative to mean tropical SST is the more physically relevant metric (Swanson, 2008). The distinction is an important one when making projections of power dissipation based on projections of SST, particularly in the Atlantic where SST has been increasing more rapidly than the tropics as a whole (Vecchi et al., 2008).

Increases in tropical water vapor and rainfall (Trenberth et al., 2005; Lau and Wu, 2007) have been identified and there is some evidence for related changes in tropical cyclone-related rainfall (Lau et al., 2008a), but a clear trend in tropical cyclone rainfall has not yet been established due to a general lack of studies.

Estimates of tropical cyclone variability prior to the modern instrumental historical record have been constructed using archival documents (Chenoweth and Devine, 2008), coastal marsh sediment records and isotope markers in coral, speleothems, and tree-rings, among other methods (Frappier et al., 2007a). These estimates demonstrate centennial- to millennial-scale relationships between climate and tropical cyclone activity (Donnelly and Woodruff, 2007; Frappier et al., 2007b; Nott et al., 2007; Nyberg et al., 2007; Scileppi and Donnelly, 2007; Neu, 2008; Woodruff et al., 2008a; Woodruff et al., 2008b; Mann et al., 2009; Yu et al., 2009) but generally do not provide robust evidence that the observed post-industrial tropical cyclone activity is unprecedented.

The AR4 Summary for Policy Makers concluded that it is likely that a trend had occurred in intense tropical cyclone activity since 1970 in some regions (IPCC, 2007b). In somewhat more detail, it was further stated that "*there is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical SSTs. There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. There is no clear trend in the annual numbers of tropical cyclones*." The subsequent U.S. CCSP SAP 3.3 (Kunkel et al., 2008) concluded that "*Atlantic tropical storm and hurricane destructive potential as measured by the Power Dissipation Index (which combines storm intensity, duration, and frequency) has increased*". *The report concludes that "the power dissipation increase is substantial since about 1970, and is likely substantial since the 1950s and 60s, in association with warming Atlantic SSTs*", and that "*it is likely that the annual numbers of tropical storms, hurricanes and major hurricanes in the North Atlantic have increased over the past 100 years, a time in which Atlantic SSTs also increased*", but that "*the evidence is not compelling for significant trends beginning in the late 1800s*". Based on research subsequent to the IPCC AR4 and CCSP SAP3.3,which further elucidated the scope of uncertainties in the historical tropical cyclone data, the most recent assessment by the World Meteorological Organization Expert Team on Climate Change Impacts on Tropical Cyclones (Knutson et al., 2010) does not assign a likely confidence level to the reported increases in annual numbers of tropical storms, hurricanes and major hurricanes counts over the past 100 years in the North Atlantic basin, nor does it conclude that the Atlantic Power Dissipation Index increase is likely substantial since the 1950s and 60s.

Our assessment regarding observed trends in tropical cyclone activity are unchanged from the WMO report (Knutson et al., 2010):

1. It is uncertain whether any reported long-term increases in tropical cyclone frequency are robust, after accounting for past changes in observing capabilities.
2. An increase globally since 1983 in the intensities of the strongest tropical cyclones has been reported (Elsner et al., 2008); however, the short time period of the data does not allow for a convincing detection and attribution of an anthropogenic signal compared with variability from natural causes.
3. A detectable change in tropical cyclone-related rainfall has not been established by existing studies.
4. There is no conclusive evidence that any observed changes in tropical cyclone genesis, tracks, duration, or surge flooding exceed the variability expected from natural causes.

3.4.4.2. Causes Behind the Changes

In addition to the natural variability of tropical SSTs, several studies have concluded that there is a detectable tropical SST warming trend due to increasing greenhouse gases (Karoly and Wu, 2005; Knutson et al., 2006; Santer et al., 2006; Gillett et al., 2008a). The region where this anthropogenic warming has occurred encompasses tropical cyclogenesis regions, and the CCSP SAP 3.3 report (CCSP, 2008) stated that “it is very likely that human-caused increases in greenhouse gases have contributed to the increase in SSTs in the North Atlantic and the Northwest Pacific hurricane formation regions over the 20th century.” Changes in the mean thermodynamic state of the tropics can be directly linked to tropical cyclone variability within the theoretical framework of potential intensity theory (Bister and Emanuel, 1998). In this framework, the expected response of tropical cyclone intensity to observed climate change is relatively straightforward: if climate change causes an increase in the ambient potential intensity that tropical cyclones move through, the distribution of intensities in a representative sample of storms is expected to shift toward greater intensities (Emanuel, 2000; Wing et al., 2007). Such a shift in the distribution would be most evident at the upper quantiles of the distribution as the strongest tropical cyclones become stronger (Elsner et al., 2008).

Changes in tropical cyclone intensity, frequency, genesis location, duration, and track contribute to what is sometimes broadly defined as “tropical cyclone activity”. Of these metrics, intensity has the most direct physically reconcilable link to climate variability within the framework of potential intensity theory, as described above. Statistical correlations between necessary ambient environmental conditions and tropical cyclogenesis frequency have been well documented (DeMaria et al., 2001). For example, there is an apparent minimum SST threshold for genesis. However, these relationships are less formally based on physical arguments and may be neither stationary in time nor independent of other factors (Nolan et al., 2007; Knutson et al., 2008). Similarly, the pathways through which climate variability can affect tropical cyclone genesis position, duration, and tracks are not well understood, and guidance from dynamical models is still limited, although statistical correlations have been identified.

A further complication in determining cause and effect arises from the strong relationship between intensity and duration (Kossin and Vimont, 2007). Since tropical cyclones moving through a favourable environment intensify at an average rate of about 12 m s^{-1} per day (Emanuel, 2000), the lifetime maximum intensity of a storm depends on its duration, which can depend on its genesis location. There are then three distinct, but not mutually exclusive pathways inducing an upward shift in a distribution of tropical cyclone intensities: increasing mean ambient potential intensity, increasing mean intensification rate, or increasing the mean duration of the intensification periods. The first is more easily linked to climate and tested in a numerical or theoretical framework, but the mechanistic links to relate the latter two to climate variability are significantly more difficult to uncover.

Based on a variety of model simulations, the expected long-term changes in tropical cyclone characteristics under greenhouse warming is a decrease in frequency concurrent with an increase in mean intensity. One of the challenges for identifying these changes in the existing data records is that the expected changes predicted by the models are generally small when compared with changes associated with observed short-term natural variability. Based on changes in tropical cyclone intensity predicted by idealized numerical simulations with CO_2-induced tropical SST warming, Knutson and Tuleya (2004) suggested that clearly detectable increases may not be manifest for decades to come. Their argument was based on an informal comparison of the amplitude of the modelled upward trend (i.e., the signal) in storm intensity with the amplitude of the interannual variability (i.e., the noise). The recent high-resolution dynamical downscaling study of Bender et al., (2010) supports this argument and suggests that the predicted increases in the frequency of the strongest Atlantic storms may not emerge as a clear statistically significant signal until the latter half of the 21st century under SRES A1B warming scenarios.

With the exception of the North Atlantic, global tropical cyclone data is generally confined to the period from the mid-20th century to present. In addition to the limited period of record, the uncertainties in the historical tropical cyclone data (Section 3.2.1 and above) and the extent of tropical cyclone variability due to random processes and linkages with various climate modes such as El Niño, do not presently allow for the detection of any clear trends in tropical cyclone activity that can be attributed to greenhouse warming. As such, it remains unclear to what degree the causal phenomena described here have modulated post-industrial tropical cyclone activity.

The AR4 concluded that "it is more likely than not that anthropogenic influence has contributed to increases in the frequency of the most intense tropical cyclones"(Hegerl et al., 2007). Based on subsequent research that further elucidated the scope of uncertainties in the historical tropical cyclone data, no such attribution conclusion was drawn in the recent WMO report (Knutson et al., 2010), which states on p. 14 of their Supplementary Information "we do not draw such an attribution conclusion in this assessment. Specifically we do not conclude that there has been a detectable change in tropical cyclone metrics relative to expected variability from natural causes, particularly owing to concerns about limitations of available observations and limited understanding of the possible role of natural climate variability in producing low frequency changes in the tropical cyclone *metrics examined*."

The conclusions of the present report are similar to the WMO report (Knutson et al., 2010): the uncertainties in the historical tropical cyclone records and the degree of tropical cyclone variability — comprising random processes and linkages to various natural climate modes such as El Niño — do not presently allow for the attribution of any observed changes in tropical cyclone activity to anthropogenic influences.

3.4.4.3. Projected Changes and Uncertainties

The AR4 concluded (Meehl et al., 2007b) that "*results from embedded high-resolution models and global models, ranging in grid spacing from 100 km to 9 km, project a likely increase of peak wind intensities and notably, where analysed, increased near-storm precipitation in future tropical cyclones. Most recent published modelling studies investigating tropical storm frequency simulate a decrease in the overall number of storms, though there is less confidence in these projections and in the projected decrease of relatively weak storms in most basins, with an increase in the numbers of the most intense tropical cyclones*." The conclusions here are similar to those in the AR4, but somewhat more detail is now possible.

The spatial resolution of models such as the CMIP coupled ocean-atmosphere models used in the AR4 is generally not high enough to accurately resolve tropical cyclones, and especially to simulate their intensity (Randall et al., 2007). Higher resolution global models have had some success in reproducing tropical cyclone-like vortices (e.g., Chauvin et al., 2006; Oouchi et al., 2006; Zhao et al., 2009), but only their coarse characteristics. Significant progress has been recently made, however, using downscaling techniques whereby high-resolution models capable of reproducing more realistic tropical cyclones are run using boundary conditions provided by either reanalysis data sets or output fields from lower resolution climate models such as those used in the AR4 (e.g., Knutson et al., 2007; Emanuel et al., 2008;

Knutson et al., 2008; Emanuel, 2010). A recent study by Bender et al., (2010) applies a cascading technique that downscales first from global to regional scale, and then uses the simulated storms from the regional model to initialize a very high resolution hurricane forecasting model. These downscaling studies have been increasingly successful at reproducing observed tropical cyclone characteristics, which provides increased confidence in their projections, and it is expected that more progress will be made as computing resources improve.

While it remains uncertain whether long-term past changes in global tropical cyclone activity have exceeded the variability expected through natural causes (Knutson et al., 2010), theory (Emanuel, 1987) and idealized dynamical models (Knutson and Tuleya, 2004) predict increases in tropical cyclone intensity under greenhouse warming. The recent simulations with high-resolution dynamical models (Oouchi et al., 2006; Bengtsson et al., 2007; Gualdi et al., 2008; Knutson et al., 2008; Sugi et al., 2009; Bender et al., 2010) and statistical-dynamical models (Emanuel, 2007) consistently find that greenhouse warming causes tropical cyclone intensity to shift toward stronger storms by the end of the 21st century. These models also consistently project little change or a reduction in overall tropical cyclone frequency, but with an accompanying substantial fractional increase in the frequency of the strongest storms and increased precipitation rates. Mean 21st century global cyclone intensity changes under conditions roughly equivalent to A1B emissions scenarios are projected between 3 and 11%, and a decrease of –6 to –34% is projected in global tropical cyclone frequency. The downscaling experiments of Bender et al., (2010), which, as described above, use an ensemble of AR4 MMD simulations to nudge a high-resolution dynamical model (Knutson et al., 2008) that is then used to initialize a very high-resolution dynamical model, project a 28% reduction in the overall frequency of Atlantic storms and a 75% increase in the frequency of Saffir-Simpson category 4 and 5 hurricanes. In addition to a decrease in frequency and an increase in intensity, higher resolution models also consistently project increased precipitation rates (~20%) within 100 km of storm centers.

Another type of projection that is sometimes inferred from the literature is based on extrapolation of an observed statistical relationship. These relationships are typically constructed on past observed variability that represents a convolution of anthropogenically forced variability and natural variability across a broad range of timescales. In general however, these relationships cannot be expected to represent all of the relevant physics that control the phenomena of interest, and their extrapolation beyond the range of the observed variability they are built on is not reliable. As an example, there is a strong observed correlation between local SST and tropical cyclone power dissipation (Emanuel, 2007). If 21st century SST projections are applied to this relationship, power dissipation is projected to increase by about 300% in the next century. Alternatively, there is a similarly strong relationship between power dissipation and relative SST, which represents the difference between local and globally-averaged SST and has been argued to serve as a proxy for local potential intensity (Vecchi and Soden, 2007a). When 21st century projections of relative SST are considered, this latter relationship projects almost no change of power dissipation in the next century (Vecchi et al., 2006). Both of these statistical relationships can be reasonably defended based on physical arguments but it is not clear which, if either, is correct.

While projections under 21st century greenhouse warming indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, an increase in mean tropical cyclone maximum wind speed (+3 to +11% globally) is likely, although increases may not occur in all tropical regions (Knutson et al., 2010). It is more likely than not that the frequency of the most intense storms will increase by more than 11% in some ocean basins. As noted above in 3.4.4.1, observed changes in tropical cyclone-related rainfall have not been clearly established. However, as water vapour in the tropics increases (Trenberth et al., 2005) there is an expectation for increased tropical cyclone-related rainfall in response to associated moisture convergence increases (Held and Soden, 2006; see also Section 3.3.1.2). This increase is expected to be compounded by increases in intensity as dynamical convergence under the storm is enhanced. Models are highly consistent in projecting increased rainfall within the area near the tropical cyclone center under 21st century warming, with increases of +3% to +37% (Knutson et al., 2010). Typical projected increases are near +20%. Based on the level of consistency among models, and physical reasoning, it is likely that tropical cyclone-related rainfall rates will increase with greenhouse warming.

When simulating 21st century warming under the A1B emission scenario (or a close analogue), the present models and downscaling techniques as a whole are consistent in projecting 1) decreases or no change in tropical cyclone frequency, 2) increases in intensity and fractional increases in number of most intense storms, and 3) increases in tropical cyclone-related rainfall rates. Differences in regional projections lead to lower confidence in basin-specific projections of intensity, rainfall, and confidence is particularly low for projections of frequency within individual basins. Current models project frequency changes ranging from -6 to -34% globally, and up to ± 50% or more in individual basins by the late 21st century. There is low confidence in projections of changes in tropical cyclone genesis, location, tracks, duration, or areas of impact, and existing model projections do not show dramatic large-scale changes in these features.

3.4.5. Extratropical Cyclones

Extratropical cyclones (synoptic scale low pressure systems) exist throughout the mid-latitudes in both hemispheres and mainly develop over the oceanic basins in the proximity of the upper tropospheric jet streams or as a result of flow over mountains (lee cyclogenesis). They may be accompanied by adverse weather conditions such as windstorms, the build up of waves and storm surges or extreme precipitation events. In addition, they are the main poleward transporter of heat and moisture. Thus, changes in the intensity of extratropical cyclones or a systematic shift in the geographical location of extratropical cyclone activity may have a great impact on a wide range of regional climate extremes as well as the long-term changes in temperature and precipitation. Extratropical cyclones mainly form and grow via baroclinic instability such as a disturbance along a zone of strong temperature contrast, which is a reservoir of potential energy that can be converted into the kinetic energy associated with extratropical cyclones. In addition, intensification of the system may also take place due to latent heat release or other diabatic processes (Gutowski et al., 1992).

3.4.5.1. Observed Changes

The AR4 noted a likely net increase in frequency/intensity of Northern Hemisphere extreme extratropical cyclones and a poleward shift in the tracks since the 1950s (Trenberth et al., 2007, Table 3.8), and report on several papers showing increases in the number or strength of intense extratropical cyclone both over the North Pacific and the North Atlantic storm track (Trenberth et al., 2007, p. 312), during the last 50 years.

Studies using reanalyses indicate a northward shift in the Atlantic cyclone activity during the last 60 years with both more frequent and more intense wintertime cyclones in the high-latitude Atlantic (Weisse et al., 2005; Wang et al., 2006a; Schneidereit et al., 2007; Raible et al., 2008; Vilibic and Sepic, 2010) and fewer (Wang et al., 2006a; Raible et al., 2008) in the mid latitude Atlantic. The increase in high latitude cyclone activity is also reported in several studies of Arctic cyclone activity (Zhang et al., 2004c; Sorteberg and Walsh, 2008), but the magnitude and even the existence of the changes may depend on the choice of reanalysis (Simmonds et al., 2008).

Since the AR4 several studies of historical coastal European storminess based on the 99th and 95th percentiles of pressure tendencies or geostrophic wind deduced from triangles of pressure stations have documented large decadal variability in the storminess (Andrade et al., 2008; Hanna et al., 2008; Matulla et al., 2008; Wang et al., 2008; Allan et al., 2009; Barring and Fortuniak, 2009). Periods with peak storminess vary for different regions and there are no long-term trends over the century that are consistent among the different studies. There is however a tendency for increased storminess around 1900 and in the 1990s while the 1960s and 1970s were periods of low storm activity.

Long term in situ observations of north Pacific extreme cyclones are considerably fewer than for the Atlantic cyclones. Bromiski et al., (2003) provided an estimate of the variation in ‘‘storminess’’ from 1858 to 2000 using an hourly tide gauge record from San Francisco (West Coast, U.S.). They noted no substantial change in the monthly non-tide residuals (NTR), but a significant increasing trend in the highest 2% of extreme winter NTR since about 1950. The increasing trend in the extreme NTR was also noted by Menendez et al., (2008) using significant wave height from 26 buoys between 30–45°N near the western coast of the U.S. covering the period 1985–2007. Years having high NTR were linked to a large-scale atmospheric circulation pattern, with intense storminess associated with a broad, south-easterly displaced, deep Aleutian low that directed storm tracks toward the western U.S. coast. This is in line with the study of Graham and Diaz (2001) using reanalysis and in situ data for the last 50 years which noted a significant increase in the number and intensity of north Pacific wintertime intense extratropical cyclone systems since the 1950s. This trend was accompanied by an eastward shift and an intensification of the Aleutian Low from the mid-1970s when a generally anticyclonic period gave way to more intense cyclonic activity (Favre and Gershunov, 2006). The study of Raible et al., (2008) points in the same direction as the above-mentioned studies showing increased intensity of Pacific extratropical cyclones in all seasons during the 1958–2001 period. It should be noted that by using MSLP observations made by ships, Chang (2007) found trends in the Pacific to be much smaller than that found in the NCEP reanalysis.

Using hourly mean sea level pressure data observed at 83 Canadian stations for up to 50 years (1953–2002), Wang et al., (2006a) showed that winter cyclones have become significantly more frequent, longer lasting, and stronger in the lower Canadian Arctic, but less frequent and weaker in the south, especially along the southeast and southwest coasts. Winter cyclone deepening rates were reported to increase in the zone around 60°N but decreased in the Great Lakes area and southern Prairies–British Columbia. Using a longer time period (1900 to 1990), Angel and Isard (1998) reported a significant annually and cold season increase in the number of strong cyclones across the Great Lakes. This seems to contradict the findings of Wang et al., (2006a), but also the Angel and Isard study finds a slight decrease since the 1950s. Studying U.S. East Coast winter cyclones using reanalyses, Hirsch et al., (2001) found a tendency toward weaker low-pressure systems over the past few decades and no statistically significant trends in their frequency.

Studies on extratropical cyclone activity in northern Asia are few. Zhang et al., (2004c) noted a decrease in cyclone activity (a parameter integrating cyclone intensity, number and duration) over Eurasia (60–40°N) over the period 1948-2002, while Wang et al., (2008) reported on deceasing trends in intensity (1958–2001) of seasonal and annual extratropical cyclones in the eastern part of Eurasia (80-140°E and 60–40°N). Wang et al., (2008) also noted a northward shift with increased cyclone frequency in the higher latitudes (50–45°N) and decrease in the lower latitudes (south of 45°N), based on a study with reanalyses. The low latitude (south of 45°N) decrease was also noted by Zou et al., (2006) which reported a decrease in the number of severe storms for mainland China using the 95th and 99th percentiles of observed 6-hourly pressure changes (1954 – 2004).

Using reanalyses, Pezza et al., (2007) confirms previous studies showing a trend towards fewer and more intense systems in the Southern Hemisphere. A new study (Lim and Simmonds, 2009) using the ERA-40 reanalysis instead of the NCEP reanalysis used in previous studies, confirms the trend towards more intense systems, but does not support the decrease in cyclone density seen in previous studies. This emphasises the weaker consistency among reanalysis products for the Southern Hemisphere extratropical cyclones and the possibility of some of the trends being biased by data inhomogeneities (Wang et al., 2006a). Wang et al., (2006a) noted a poleward shift in storm tracks in the Southern Hemisphere, confirming previous studies (Fyfe, 2003; Hope et al., 2006) and Alexander and Power (2009) show that the number of observed severe storms at Cape Otway (south-east Australia) has decreased significantly since the mid-19th century, strengthening the evidence of a southward shift in Southern Hemisphere storm tracks. Fredriksen and Fredriksen (2007) linked the reduction in cyclogenesis at 30°S and southward shift to a decrease in the vertical mean meridional temperature gradient.

In summary, research subsequent to the AR4 supports previous findings of a poleward shift in the tracks, but do not provide sufficient information to increase the degree of confidence in the assessment. There are few post AR4 studies on global changes in the intensity of extreme cyclones, but there is growing evidence of a intensification of extratropical cyclones in high-latitudes. Trends in the total number of cyclones are less clear and seem more sensitive to tracking scheme, choice of physical quantity to represent the cyclone and choice of reanalysis data set. New insight into the regional variability and trends in extratropical cyclones has emerged since AR4. In the Atlantic, studies using reanalysis points toward a northward shift in the cyclone activity during the last 60 years with both more and more intense wintertime cyclones in the high-latitude Atlantic, but there is no clear overall increase in number or intensification if the whole Atlantic is considered. The Atlantic trends should be seen in light of new studies with longer time spans indicating that the reanalysis cover a time period which starts with relatively low cyclonic activity in northern coastal Europe in the 1960s and reaches a maximum in the 1990s. For the Pacific, new studies indicate a increase in intensity and there are indications that this is accompanied by an eastward shift in the Aleutian Low. New studies on Southern Hemisphere extratropical cyclones confirm previous studies reporting a poleward shift and a possible intensification of the Southern Hemisphere cyclones. However, the latter conclusion relies on reanalysis products that may contain inhomogeneities affecting the Southern Hemisphere trend estimates. Advances have been made in documenting the observed decadal and multidecadal variability of cyclones (Andrade et al., 2008; Hanna et al., 2008; Matulla et al., 2008; Allan et al., 2009; Barring and Fortuniak, 2009), but insufficient knowledge of the observed decadal and multidecadal variability and how the influence of reanalysis inhomogeneities are influencing cyclone number and intensity trends over the last 50 years is still limiting our confidence in understanding historical extratropical cyclone changes.

3.4.5.2. Causes Behind the Changes

Regarding possible causes of trends, the AR4 concluded that trends over recent decades in the Northern and Southern Annular Modes, which correspond to sea level pressure reductions over the poles, are likely related in part to human activity, affecting storm tracks, winds and temperature patterns in both hemispheres. Simulated and observed changes in extratropical cyclones are broadly consistent, but an anthropogenic influence has not yet been detected, owing to large internal variability and problems due to changes in observing systems (Hegerl et al., 2007).

New studies have advanced the physical understanding of how stormtracks may respond to changes in the underlying surface condition and external forcing and seem to support the notion that average global cyclone activity may not be expected to change much under moderate greenhouse gas forcing. Idealized model simulations indicate that a uniform SST increase weakens (reduced cyclone intensity or density) and shifts the stormtrack poleward (Kodama and Iwasaki, 2009), and strengthened SST gradients near the subtropical jet may lead to a meridional shift in the stormtrack either towards the poles or the equator depending on the location of the SST gradient change (Brayshaw et al., 2008). By varying the longwave optical thickness as a proxy for changes in greenhouse gasses, O'Gorman and Schneider (2008) found that eddy kinetic energy is fairly insensitive to changes in radiative forcing near the present climate. These idealized experiments are consistent with the single model study of Bengtsson, et al., (2009) using a higher resolution AGCM.

Large-scale circulation anomalies and cyclone activity are closely connected. Several new studies confirmed that positive (negative) NAM/NAO corresponds to stronger (weaker) Atlantic/European cyclone activity (e.g., Chang, 2009; Pinto et al., 2009). However, studies using long historical records also seem to suggest that some of these links are intermittent (Hanna et al., 2008; Matulla et al., 2008; Allan et al., 2009). This possible nonstationary relationship between cyclone activity and NAO has been linked to interdecadal shifts in the location of the positions of the NAO pressure centers (Vicente-Serrano and Lopez-Moreno, 2008; Zhang et al., 2008b). Cyclone activity in Canada was found to closely co-vary with the states of NAO, the PDO, and the ENSO (Wang et al., 2006a). North Pacific cyclonic activity has been linked to tropical SST anomalies (NINO3.4) and PNA (Eichler and Higgins, 2006; Favre and Gershunov, 2006; Seierstad et al., 2007), showing that the PNA and NINO3.4 influence storminess and in particular over the eastern north Pacific. During El Niño events, there is an equatorward shift in storm tracks in the North Pacific basin, as well as an increase of storm track activity along the U.S. East Coast. Seierstad et al., (2007) noted that the relationship between NAO and storminess may to a large extent be accounted for by a basic relation between storminess and the local mean sea level pressure, indicating that the cause and effect of the association between the NAO and cyclonic activity is unclear. On the other hand they identified the PNA to be an important non-local factor for storminess north of the Aleutian Low. In the Southern Hemisphere, cyclone activity is related to the SAM with more cyclones around Antarctica when the SAM is in its positive phase, but more cyclones toward midlatitudes when the SAM is in its negative phase. More recent studies support this notion (Pezza and Simmonds, 2008). Additionally, more intense (and fewer) cyclones seem to occur when the PDO is strongly positive and vice versa (Pezza et al., 2007).

In summary, some changes in extratropical cyclones are related to variations in the modes of variability discussed in Sections 3.4.2 and 3.4.3. AR4 noted that observed changes in NAM and SAM are inconsistent with simulated internal variability (Hegerl et al., 2007). Anthropogenic influence on the sea level pressure distribution has also been detected in individual seasons (Giannini et al., 2003; Gillett et al., 2005; Wang et al., 2009c). Thus changes in these modes of variability may be affecting changes in extratropical cyclone occurrence. Some evidence has been found for changes in atmospheric storminess. The trend pattern in atmospheric storminess as inferred from geostrophic wind energy and ocean wave heights has been found to contain a detectable response to anthropogenic and natural forcings with the effect of external forcings being strongest in the winter hemisphere (Wang et al., 2009c). However, they note that climate models generally simulate smaller changes than observed and also appear to under-estimate the internal variability, reducing the robustness of their detection results.

Improved physical understanding of how stormtracks may respond to changes in SSTs and increased greenhouse gases (Deser et al., 2007; Brayshaw et al., 2008; Semmler et al., 2008; Kodama and Iwasaki, 2009) strengthen the notion that anthropogenic forcing may cause regional changes in both number of extratropical cyclones and intensity. Though the trend pattern in atmospheric storminess and ocean wave height contains a detectable response to anthropogenic forcing, it is still not possible to separately detect the effects of different external forcings. This new evidence has strengthened but does not alter the AR4 assessment that it is *likely* that anthropogenic forcing has contributed to the changes in extratropical storm tracks, because simulated and observed changes in extratropical cyclones are broadly consistent, but that a quantitative anthropogenic influence has not yet been detected formally, owing to large internal variability and problems due to changes in observing systems.

3.4.5.3. Projected Changes and Uncertainties

The AR4 reports that for a future warmer climate, a consistent projection from the majority of the coupled atmosphere-ocean GCMs is fewer mid-latitude storms averaged over each hemisphere (Meehl et al., 2007b), a poleward shift of storm tracks in both hemispheres (particularly evident in the Southern Hemisphere), with greater storm activity at higher latitudes (Meehl et al., 2007b). Idealized studies (e.g., Deser et al., 2007; Lorenz and DeWeaver, 2007; Brayshaw et al., 2008; O'Gorman and Schneider, 2008; Kodama and Iwasaki, 2009) and diagnostic studies (Laine et al., 2009; Lim and Simmonds, 2009) on the response of extratropical cyclone changes to changes in radiative forcing or surface characteristics has provided new insight that can be used to understand the different model responses, but in depth analysis of changes in physical mechanisms related to cyclone changes in coupled climate models is still limited, and the inter-model differences are not well understood. This is complicated by the fact that studies use different analysis techniques, different physical quantities, different thresholds and different atmospheric vertical levels to represent cyclone activity and storm tracks (Raible et al., 2008). This diversity highlights different aspects of the cyclones, but makes it difficult to combine the results into a common view of future extratropical cyclone changes.

The Northern Hemisphere poleward shift in the stormtrack is supported by post-AR4 studies (Lorenz and DeWeaver, 2007). However, the strength of the poleward shift is often seen more clearly in upper-level mean quantities such as monthly zonal winds in 300hPa than in low-level transient parameters. Using bandpassed mean sea level pressures from 16 AR4 coupled GCMs, Ulbrich et al., (2008) show a wintertime poleward shift of stormtrack activity in some regions. It should be noted that other studies indicate that the poleward shift is less clear when models including a full stratosphere (Huebener et al., 2007) and ozone recovery (Son et al., 2008) are used. Post AR4 single model studies support the projection of a reduction in mid-latitude cyclones averaged over each hemisphere during future warming (Finnis et al., 2007; Bengtsson et al., 2009; Orsolini and Sorteberg, 2009). However, neither the global changes in storm frequency or intensity are found to be statistically significant by Bengsston et al., (2009), although they are accompanied by significant increases in total and extreme precipitation.

Models tend to show a northern movement of the North Pacific storm track (Loeptien et al., 2008; Ulbrich et al., 2008; Favre and Gershunov, 2009). However, the exact geographical pattern of cyclone frequency anomalies exhibits large variations across models. Some show indications of increased frequency along the U.S. west coast (Teng et al., 2008; Laine et al., 2009) while others show opposite results (Favre and Gershunov, 2009).

The large-scale response of cyclones in the North Atlantic is less clear than over the North Pacific. While some models exhibit a northward movement of the stormtracks (Pinto et al., 2007; Teng et al., 2008; Long et al., 2009; Orsolini and Sorteberg, 2009) others show more of an eastward extension (Ulbrich et al., 2008; Laine et al., 2009). In contrast, Huebner et al., (2007) report a southward shift in the North Atlantic stormtrack using a coupled model with a full stratosphere. Models showing a northward movement of the stormtrack tend to report a reduction in cyclone frequency along the Canadian east coast (Bengtsson et al., 2006; Watterson, 2006; Pinto et al., 2007; Teng et al., 2008; Long et al., 2009) consistent with changes observed during 1958–2001, reported by Wang et al., (2006a). A more detailed analysis of the AR4 MME for Europe, indicates an increase of between 18 and 62% in the number of storm days (the increase varies according to the definition of storminess and one model shows a decrease) associated with increased frequency of westerly flow (Donat et al., 2009). The mean intensity of storm cyclones increases by about 10% in the Eastern Atlantic, close to the British Isles and into the North Sea – increases which are also reflected in wind speed changes in these regions (Section 3.3.3).

In depth analysis of mechanisms responsible for projected regional changes in cyclone density and intensity are few. Using two coupled climate models, Laine et al., (2009) indicate that the primary cause for synoptic activity changes at the western end of the storm tracks is related to the baroclinic conversion processes linked to mean temperature gradient changes in localized regions of the western oceanic basins. Further downstream changes in latent heat release during the developing and mature stages of eddy are also important. They indicate that changes in diabatic process may be amplified by the upstream synoptic changes (stronger (weaker) baroclinic activity in the west gives stronger (weaker) latent heat release downstream).

New results on Southern Hemisphere cyclones confirm the previously projected poleward shift in stormtracks under increased greenhouse gases (Lim and Simmonds, 2009). They report a reduction of Southern Hemisphere extratropical cyclone frequency and intensity in midlatitudes but a slight increase at high latitude. The midlatitude changes were attributed to the tropical upper tropospheric warming enhancing static stability which decreases baroclinicity while an increased meridional temperature gradient in the high latitudes may be responsible for the increase of cyclone activity in this region (Lim and Simmonds, 2009).

In summary, it is *likely* that future anthropogenic climate change may influence cyclone activity through its impact on upper and lower level baroclinity and diabatic heating. A reduction in the number of mid-latitude cyclone averaged over each hemisphere is likely and it is *more likely than not* that high-latitude cyclone number and intensity will increase. It should be noted that the projected changes are fairly modest compared to interannual variability.

Regional changes may be substantial, but there is little consistency between models on the geographical pattern of cyclone activity changes. This leads to lower confidence in region-specific projections. The geographical pattern of modelled response in cyclone activity to various forcing is likely to be influenced by the individual model's structure of intrinsic modes of variability (Branstator and Selten, 2009) as well as details in the modelled changes in local baroclinicity and diabatic changes. However, models tend to show a poleward shift over the Southern Hemisphere, and a poleward and eastward shift of the North Pacific extratropical cyclones. Changes in low-level cyclone activity over the North Atlantic are less consistent, with some models showing an eastward extension while others have a poleward shift. New diagnostic studies (Laine et al., 2009; Lim and Simmonds, 2009) on the response of extratropical cyclone changes to changes in radiative forcing or surface characteristics has provided new insight that can be used to understand the different model responses, but in depth analysis of changes in physical mechanisms related to cyclone changes in coupled climate models is still limited, and the inter-model differences are not well understood. This is further complicated by the fact that studies use different analysis techniques, different physical quantities, different thresholds and different atmospheric vertical levels to represent cyclone activity and storm tracks (Raible et al., 2008). This diversity highlights different aspects of the cyclones, but makes it difficult to combine the results into a common view of future extratropical cyclone changes.

3.5. Observed and Projected Impacts on the Natural Physical Environment

3.5.1. Droughts

Drought is generally caused by 'a period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance' (Heim Jr, 2002; IPCC, 2007a, glossary) and has been defined from different perspectives, e.g., meteorological drought related to deficit of precipitation, agricultural drought related to root zone soil water balance, or hydrological drought related to streamflow, lake and groundwater levels (e.g., Heim Jr, 2002). While lack of precipitation (i.e., meteorological drought) is often the primary precondition (see above definition), increased evapotranspiration (e.g., Easterling et al., 2007; Corti et al., 2009) as well as preconditioning (pre-event soil moisture and/or groundwater storage) are critical factors that can contribute to the emergence of agricultural and hydrological drought (Figure 3.11). As noted in the AR4 (Trenberth et al., 2007), there are few direct observations of drought-related variables, in particular of soil moisture, available for a global analysis (see also Section 3.2.1). Hence, proxies for drought are often used to infer changes in drought conditions. These proxies include indices such as the Palmer Drought Severity Index (PDSI) (Palmer, 1965) or the Standard Precipitation Index (SPI) (McKee et al., 1993; Lloyd-Hughes and Saunders, 2002), land-surface model simulations (e.g., Sheffield and Wood, 2008), and paleoclimate proxies such as tree rings. Hence, drought indices often integrate temperature, precipitation and other variables, but may be problematic when not integrating all necessary information (Nicholls and Alexander, 2007). In order to understand the impact of droughts (e.g., on crop yields, general ecosystem functioning, etc.), the timing, the duration and intensity need to be characterized. The maximum number of consecutive dry days is often used as an overall drought index for a whole year, while other indices such as the PDSI characterize specific situations within a year. Other weather elements may interact to increase the impact of droughts (see also Figure 3.11): Enhanced air temperature leads to enhanced evaporative demand, as does enhanced wind speed. Moreover, climate phenomena such as monsoons (Section 3.4.1) and ENSO (Section 3.4.2) affect changes in drought occurrence in some regions. Hence, drought is a complex phenomenon that is strongly affected by other extremes considered in this Chapter. Moreover, via land-atmosphere interactions, drought also has the potential to feedback and exacerbate other weather and climate elements such as temperature and precipitation (Koster et al., 2004b; Seneviratne et al., 2006a) (see also Section 3.1.5 and Box 3.4).

3.5.1.1. Observed Changes

The AR4 reports that very dry areas (PDSI < -3) more than doubled in extent since 1970 on the global scale (Trenberth et al., 2007). However from a paleoclimate perspective recent droughts are not unprecedented with severe “mega droughts” reported in the paleoclimatic record for Europe, North America and Australia. Recent studies extend this observation to African and Indian droughts (Sinha et al., 2007; Shanahan et al., 2009): Much more severe and longer droughts occurred in the past centuries with widespread ecological political and socioeconomic consequences. Overall these studies confirm that in the last millennium several extreme droughts (often associated with very warm air temperature) have occurred (Breda and Badeau, 2008; Kallis, 2008); hence the current situation is not unprecedented.

INSERT FIGURE 3.11 HERE

Figure 3.11: Processes and interactions involved in meteorological, agricultural, and hydrological droughts (red: positive impacts; blue: negative impacts). Dashed lines denote indirect feedbacks of soil moisture on temperature and precipitation. For simplicity, the role of interactions with other variables of the Figure (e.g., evapotranspiration, relative humidity) in these feedbacks, and feedbacks of soil moisture to other meteorological variables (e.g., circulation anomalies) are not highlighted.

Globally, 2–3 fold increases of area affected by extreme or severe droughts have been inferred by a modelling study which reproduced the global drying trend (PDSI) since the 1950s (Burke et al., 2006). This trend in the PDSI proxy is largely affected by the changes in temperature, not precipitation. Beniston (2009) found a strong increase in warm-dry mode over all central-southern (incl. maritime) Europe via a quartile-analysis from mid- to the end of the 20th century. Trends of decreasing precipitation and discharge are consistent with increasing salinity in the Mediterranean, indicating a trend towards fresh water deficits (Mariotti et al., 2008), but this could also be partly caused by increased human water-use. In France, an analysis based on a variation of the PDSI model also reported a significant increasing trend in drought conditions, in particular from the 1990s onward (Corti et al., 2009). The exceptional 2003 summer heat wave on the European continent (see Section 3.3.1) was also associated with a major drought, as could be inferred from satellite measurements (Andersen et al., 2005), model simulations (Fischer et al., 2007a; Fischer et al., 2007b), and impacts on ecosystems (Ciais et al., 2005; Reichstein et al., 2007). In the U.S., droughts are becoming more severe in some regions, but there are no clear trends for North America as a whole (Kunkel et al., 2008; Wang et al., 2009b), with an observational record dating back to 1895. The most severe droughts have occurred in the 1930s in the U.S. and Canada, while in Mexico the 1950s and late 1990s were the driest periods. Recent regional trends towards more severe drought conditions are observed over southern and western Canada, Alaska and Mexico. Furthermore, Easterling et al., (2007) showed that the increase in precipitation in the continental USA has masked an increasing tendency for more droughts due to increasing temperatures. For the Amazon, repeated strong droughts have been occurring in the last decades but no particular trend has been reported. The 2005 drought in Amazonia is however considered the strongest in the last century both from precipitation records and water storage estimates via satellite (measurements from the Gravity Recovery and Climate Experiment (GRACE)), (Chen et al., 2009). For other parts of South America analyses of the return intervals between droughts in the instrumental and reconstructed precipitation series indicate that the probability of drought has increased during the late 19th and 20th centuries, consistent with selected long instrumental precipitation records and with a recession of glaciers in the Chilean and Argentinian Andean Cordillera (Le Quesne et al., 2006; Le Quesne et al., 2009). Changes in drought patterns have been reported for the monsoon regions of Asia and Africa with variations at the decadal timescale (e.g., Janicot, 2009). In the Sahel, recent years are characterized by a greater interannual variability than the previous 40 years (Ali and Lebel, 2009; Greene et al., 2009), and by a contrast between the western Sahel remaining dry and the eastern Sahel returning to wetter conditions (Ali and Lebel, 2009). Giannini et al., (2008) report a drying of the monsoon regions, related to warming of the tropical oceans, and variability related to the El Niño–Southern Oscillation.

In conclusion, the assessment of the AR4 that since the 1950s and in particular the 1970s it is *likely* that more intense and longer droughts have occurred over larger areas and generally in the Northern Hemisphere (Trenberth et al., 2007) has been supported by post-AR4 research analyzing regional drought.

3.5.1.2. Causes Behind the Changes

AR4 (Hegerl et al., 2007) also concludes that it is *more likely than not* that anthropogenic influence has contributed to the increase in the droughts observed in the second half of the 20th century. This assessment was based on multiple lines of evidence: a detection study identified an anthropogenic fingerprint in a global PDSI data set with high significance (Burke et al., 2006), and studies of some regions indicate that droughts in those regions are linked either to SST changes that, in some instances, may be linked to anthropogenic aerosol forcing (e.g., Sahel) or to a circulation response to anthropogenic forcing (e.g., southwest Australia).

There is now a better understanding of the potential role of land-atmosphere feedbacks versus SST forcing for droughts (e.g., Schubert et al., 2008a; Schubert et al., 2008b) as well as of potential impacts of land use changes (Deo et al., 2009), but large uncertainties remain in the field of land surface modelling and land-atmosphere interactions, in part due to lack of observations (Seneviratne et al., 2010) and inter-model discrepancies (Koster et al., 2004b; Dirmeyer et al., 2006; Pitman et al., 2009). Nonetheless, a new set of climate modelling studies show that U.S. drought response to SST variability is consistent with observations (Schubert et al., 2009). It has been suggested that the stomatal "antitranspirant" responses of plants to rising atmospheric CO_2 may lead to a decrease in evapotranspiration (Gedney et al., 2006), but this result is still debated. Additionally, model-dependent results regarding past trends, which could point to deficiencies in the relevant parameterizations, cannot be credibly compared with observations, due to the lack of reliable globally-available runoff and evapotranspiration observations (e.g., Peel and McMahon, 2006; Teuling et al., 2009). Inferred trends in drought are also consistent with trends in global precipitation and temperature, and the latter two are consistent with expected responses to anthropogenic forcing (Hegerl et al., 2007; Zhang et al., 2007a). The change in the pattern of global precipitation in the observations and in model simulations are also consistent with theoretical understanding of hydrological response to global warming that wet regions become wetter and dry regions drier in a warming world (Held and Soden, 2006). However, the recent U.S. drought that began in the 2005/2006 winter in the southeastern U.S. is different from what would be expected from model projected anthropogenic climate change in this region: The drought was caused by a reduction in precipitation (with simultaneous reduction in evaporation), but models project an increase in precipitation minus evaporation (Seager et al., 2009). Though these new studies have improved the understanding of the mechanisms leading to drought, there is still not enough evidence to alter the AR4 assessment, in particular given the associated observational data issues (Section 3.2.1).

3.5.1.3. Projected Changes and Uncertainties

AR4 model projections indicate an increase in droughts in particular in subtropical and mid-latitude areas (Christensen et al., 2007). An increase in dry spell length and frequency is considered very likely over the Mediterranean area, southern areas of Australia and New Zealand and likely over most subtropical regions, with little change over northern Europe. Continental drying and the associated risk of drought are considered likely to increase in summer over many mid-latitude continental interiors (e.g., central and southern Europe, the Mediterranean), in boreal spring and dry periods of the annual cycle over Central America. More recent global and regional climate simulations support the projections from AR4, as summarized in the following paragraphs.

Particular care is needed in intercomparing 'drought' projections since very many different definitions are employed (corresponding to different types of droughts), from simple climatic indices such as maximum consecutive dry days to more complex indices of hydrological and agricultural drought (see above). A distinction also needs to be made between short-term and longer-term events. Blenkinsop and Fowler (2007), for example, demonstrate that while an RCM ensemble indicate an increase in short-term summer drought over most of the UK, the longer (multi-season) droughts are projected to become shorter and less severe (although uncertainties in the latter projections are large – see below).

Burke and Brown (2008) project an increase in the global area affected by extreme drought from 1% to 21% over the 21st century. However, the changes are dependent on the definition of the drought index. Areas where drought is indicated to increase across all indices examined include the Mediterranean, Amazonia and southern Africa. These results are consistent with findings by Sillmann and Rockner (2008) who show increasing dry spells in regions which are already affected by drought today. The consecutive dry days index increases significantly around the Mediterranean Sea, Australia and southern Africa, as well in the north-eastern part of South America and the Pacific coast of Central and South America. One GCM-based study suggests one to three weeks of additional dry days for the Mediterranean by the end of the century (Giannakopoulos et al., 2009).

Regional climate simulations over Europe also highlight the Mediterranean region as being affected by more severe droughts (Giorgi, 2006; Beniston et al., 2007; Mariotti et al., 2008; Planton et al., 2008). Mediterranean droughts are likely to start earlier in the year and last longer. Also increased variability during the dry and warm season is projected (Giorgi, 2006). For North America, intense and heavy episodic rainfall events with high runoff amounts are interspersed with longer relatively dry periods with increased evapotranspiration, particularly in the subtropics. There is consensus of most climate-model projections regarding a reduction of cool season precipitation across the U.S. southwest and northwest Mexico (Christensen et al., 2007) with more frequent multi-year drought in the American southwest (Seager et al., 2007). Reduced cool season precipitation promotes drier summer conditions by reducing the amount of soil water available for evapotranspiration in summer. For Australia, Alexander and Arblaster (2009) find increases in consecutive dry days, although consensus among the models is only found in the interior.

Increased confidence in modelling drought stems from consistency between models and satisfactory simulation of drought indices during the past century (Sheffield and Wood, 2008; Sillmann and Roeckner, 2008). Inter-model agreement is stronger for long-term droughts and larger spatial scales, while local to regional and short-term precipitation deficits are highly spatially variable and much less consistent between models (Blenkinsop and Fowler, 2007). Lack of complete knowledge of the physical causes of meteorological droughts, and links to the large-scale atmospheric and ocean circulation are still a source of uncertainty in drought simulations and projections. For example, plausible explanations have been proposed for projections of both a worsening drought and a substantial increase in rainfall in the Sahara (Biasutti and Sobel, 2009). Another example is illustrated with the relationship of rainfall in southern Australia with SSTs around northern Australia. On annual time-scales, low rainfall is associated with cooler than normal SSTs. Yet the warming observed in SST over the past few decades has not been associated with increased rainfall, but with a trend to more drought-like conditions (Nicholls, 2009).

There are still further sources of uncertainties affecting the projections of trends in meteorological drought for the coming century. The two most important may be uncertainties in the development of the ocean circulation and feedbacks between land surface and atmospheric processes. These latter processes are related to the effects of drought on vegetation physiology and dynamics (e.g., affecting canopy conductance, albedo and roughness), with resulting (positive or negative) feedbacks to precipitation formation (Findell and Eltahir, 2003a, b; Koster et al., 2004b; Cook et al., 2006; Hohenegger et al., 2009; Seneviratne et al., 2010), and possibly - as only recently highlighted – also feedbacks between droughts, fires and aerosols (Bevan et al., 2009).

Furthermore, the development of "agricultural drought" that results from complex interactions of precipitation, water storage as soil moisture (and snow), and evapotranspiration by vegetation, is still associated with large uncertainties, in particular because of lack of observations of soil moisture and evapotranspiration (Section 3.2.1), and issues in the representation of soil moisture-evapotranspiration coupling in current climate models (Dirmeyer et al., 2006; Seneviratne et al., 2010). Uncertainties regarding soil moisture-climate interactions are also due to uncertainties regarding the behaviour of plants' transpiration, growth and water-use efficiency under enhanced atmospheric CO_2 concentrations, which could potentially have major impacts on the hydrological cycle (Betts et al., 2007), but are not well established yet (Hungate et al., 2003; Piao et al., 2007; Bonan, 2008; Teuling et al., 2009).

3.5.2. Floods

Floods are natural physical impacts produced by a transient high water level along a river channel, lake or on a sea coast. When humans are impacted, floods can become "natural disasters." Floods include river floods, flash floods, urban floods, sewer floods, coastal floods, and glacial lake outburst floods (GLOFs). The main causes of floods are intense and/or long-lasting precipitation, snow/ice melt, a combination of previous types, dam break (e.g., glacial lakes), reduced conveyance due to ice jams or landslides, or by a local intense storm (Smith and Ward, 1998). Climate-related floods depend on precipitation intensity, volume, duration, timing, phase (rain or snow), antecedent conditions of rivers and their drainage basins (e.g., presence of snow and ice, soil character and status, wetness, rate and timing of snow/ice melt, urbanisation, existence of dikes, dams, and/or reservoirs) (Bates et al., 2008), while along coastal areas flooding may be associated with storm surge events. This chapter focuses on the spatial, temporal and seasonal changes in high flows and peak discharge in rivers related to climate change, while the impact of floods on human society and ecosystems and related changes are discussed in Chapter 4. Coastal floods are described as a part of the section on extreme sea level and coastal impacts (Section 3.5.5). GLOFs are discussed in Section 3.5.6.

3.5.2.1. Observed Changes

The AR4 concluded that no gauge-based evidence had been found for climate-related trend in the magnitude/frequency of floods during the last decades (Rosenzweig et al., 2007), while it noted that flood damages were increasing (Kundzewicz et al., 2007) and that an increase in heavy precipitation events was already *"likely"* in the late 20th-century trend (Trenberth et al., 2007). The AR4 also highlighted a catastrophic flood that occurred along several central European rivers in 2002 in a similar context; no significant trend in flood occurrences was found but the trend in precipitation variability was indicative of an enhancement of flood occurrence (Trenberth et al., 2007). On the other hand, the AR4 concluded that abundant evidence was found for an earlier occurrence of spring peak river flows in snow-dominated regions (Rosenzweig et al., 2007). Research subsequent to the AR4 still does not show clear and widespread evidence of observed changes in flooding at the global level based on instrumental records, except for the earlier spring flow in snow-dominated regions.

Worldwide instrumental records of floods at gauge stations are limited in spatial coverage and in time, and only a limited number of gauge stations spans more than 50 years, and even fewer over 100 years (Rodier and Roche, 1984, see also Section 3.1.1.2). Pre-instrumental flood data sources can be obtained from documentary records (archival reports, in Europe continuous over the last 500 yrs) (Brazdil et al., 2005), and from geological indicators known as paleofloods (sedimentary and biological records over centuries to millennia scales) (Kochel and Baker, 1982). Analysis of these centennial past flood records have revealed that (1) flood magnitude and frequency are very sensitive to subtle alterations in atmospheric circulation, with greater sensitivity on largest “rare” floods (50-year flood and higher) than on smaller frequent floods (2-year floods) (Knox, 2000; Redmond et al., 2002); (2) high interannual and interdecadal variability is found in flood occurrences both in terms of frequency and magnitude although in most cases, cyclic or clusters of flood occurrence are observed in instrumental (Robson et al., 1998), historical (Vallve and Martin-Vide, 1998; Benito et al., 2003; Llasat et al., 2005) and paleoflood records (Ely et al., 1993; Benito et al., 2008); (3) past flood records may contain analogues of unusual large floods, as the ones recorded recently, sometimes claimed to be the largest on record. For example, pre-instrumental flood data shows that the 2002 summer flood in the Elbe did not reach the highest flood levels recorded in 1118 and 1845 although it was higher than other disastrous floods of 1432, 1805, etc. (Brázdil et al., 2006). However, the currently available pre-instrumental flood data is also limited.

Although flood trends might be seen in the north polar region and in northern regions where temperature change affects snowmelt or ice cover, widespread evidence of this (except for earlier spring flow) is not found. For example, Cunderlik and Ouarda (2009) reported that snowmelt spring floods come significantly earlier in the southern part of Canada, and one fifth of all the analyzed stations show significant negative trends in the magnitude of snowmelt floods over the last three decades. On the other hand, there is no evidence of widespread common trends in the magnitude of extreme floods based on the daily river discharge of 139 Russian gauge stations for the last few to several decades, while a significant shift to earlier spring discharge is found as well (Shiklomanov et al., 2007).

In Europe, significant upward trends in the magnitude and frequency of floods were detected in a considerable fraction of river basins in Germany for the period 1951–2002, particularly in western, southern, and central Germany and particularly for winter floods, although there is no ubiquitous increase of floods all over Germany (Petrow and Merz, 2009). This is apparently in agreement with an upward trend in annual and winter flood discharges since 1984 in the Meuse river (northwest Germany, The Netherlands, and Belgium) and its tributaries (except Geul River) (Tu et al., 2005). Similar results are found by Allamano et al., (2009) for the Swiss Alps where they found a significant increase of flood peaks during the last century. In contrast, a slight decrease in winter floods and no change in summer maximum flow were reported in east and northeast Germany and in the Czech Republic (Elbe and Oder rivers) (Mudelsee et al., 2003). In France there is no evidence of a widespread trend in annual flow maxima over the last four decades, although there is evidence of a decreasing flood frequency trend in the Pyrenees, and increasing annual flow maxima in the northeast region (Renard et al., 2008). In Spain, southern Atlantic catchments showed a downward trend in flood magnitude and frequency, whereas in central and northern Atlantic basins no significant trend in frequency and magnitude of large floods is observed (Benito et al., 2005). Flood records from a network of catchments in the UK showed significant positive trends over the past four decades in high-flow indicators primarily in maritime-influenced, upland catchments in the north and west of the UK (Hannaford and Marsh, 2008), although in previous studies such changes were not so obvious (Robson et al., 1998). Although there are relatively abundant studies for rivers in Europe as described above, a continental scale assessment for Europe is difficult to obtain because geographically organized patterns are not seen.

The number of analyses for rivers in the other parts of the world based on the stream gauge records is limited. The limited examples in Asia are as follows; annual flood maxima of the lower Yangtze region shows an upward trend over the last 40 years (Jiang et al., 2008), an increasing likelihood of extreme floods during the last half of the century is found for the Mekong river (Delgado et al., 2009), and both upward and downward trends were detected over the last four decades in four selected river basins of the northwestern Himalaya (Bhutiyani et al., 2008). In the Amazon region in South America, the 2009 flood set record highs in the 106 years of data for the Rio Negro at the Manaus gauge site in July 2009 (Marengo, 2010). However, such analyses cover only limited parts of the world. Evidence in the scientific literature from the other parts of the world, and for other river basins, appears to be very limited.

In summary, except for the abundant evidence for an earlier occurrence of spring peak river flows in snow-dominated regions (*likely*), no clear and widespread observed evidence is found in the AR4 and research subsequent to the AR4. Besides, instrumental records of floods at gauge stations are limited in spatial coverage and in time, which limits the number of analyses. Pre-instrumental flood data can provide information for a longer period, but these data are also limited.

3.5.2.2. Causes Behind the Changes

Floods are affected by various characteristics of precipitation, such as intensity, duration, amount, timing, phase (rain or snow). They are also affected by drainage basin conditions such as water levels in the rivers, presence of snow and ice, soil character and status (frozen or not, saturated or unsaturated), wetness (soil moisture), rate and timing of snow/ice melt, urbanisation, existence of dikes, dams, and reservoirs (Bates et al., 2008). A change in the climate physically changes many of these factors affecting floods and thus may consequently change the characteristics of floods. Engineering developments such as dikes and reservoirs regulate flow, and land use may also affect floods. Therefore the assessment of causes of changes in floods is complicated and difficult.

Many river systems are not in their natural state anymore, making it difficult to separate changes in the streamflow data that are caused by the changes in climate and from those caused by human regulation of the river systems. River engineering and land use may have altered flood probability. Many dams have a function to reduce flood. However, the largest and most pervasive contributors to increased flooding on the Mississippi River system over the past 100-150 years were wing dikes and related navigational structures, followed by progressive levee construction (Pinter et al., 2008). Large dams have resulted in large scale land use change and may have changed the effective rainfall in some regions (Hossain et al., 2009).

The possible causes for changes in floods were assessed in the AR4 report. Cause-and-effect between external forcing and changes in floods has not been established. However, anthropogenic influence has been detected in the environments that affect floods, such as aspects of the hydrological cycle (e.g., Zhang et al., 2007a; see also Section 3.3.2) including precipitation and atmospheric moisture. Anthropogenic influence is also clearly detected in streamflow regimes in the western USA (Barnett et al., 2008; Hidalgo et al., 2009).

In climates where seasonal snow storage and melting plays a significant role in annual runoff, the hydrologic regime is affected by changes in temperature. In a warmer world, a smaller portion of precipitation will fall as snow (Hirabayashi et al., 2008a) and the melting of winter snow occurs earlier in spring, resulting in a shift in peak river runoff to winter and early spring. This has been observed in the western U.S. (Regonda et al., 2005; Clow, 2010) and in Canada (Zhang et al., 2001), along with an earlier breakup of river ice in Russian Arctic rivers (Smith, 2000). The observed trends toward earlier timing of snowmelt-driven streamflows in the western U.S. since 1950 are detectably different from natural variability (Barnett et al., 2008; Hidalgo et al., 2009). It is unclear if greenhouse gas emissions have affected the magnitude of the snowmelt flood peak, but projected warming may result in an increase in the spring river discharge where winter snow depth increases (Meehl et al., 2007b) or a decrease in spring flood peak (Hirabayashi et al., 2008b; Dankers and Feyen, 2009).

There is still a lack of studies identifying an influence of anthropogenic warming on peak streamflow for regions with little or no snowfall because of uncertainty in the observed streamflow data and low signal to noise ratio. However, evidence has emerged that anthropogenic forcing may have influenced the likelihood of a rainfall-dominated flood event in the UK (Pall et al., 2010). Additionally, it has been projected for many rain-dominated catchments that flow seasonality will increase, with higher flows in the peak flow season but little change in the timing of the peak or low flows (Kundzewicz et al., 2007). More recent hydrological simulation studies also show an increase in the probability of flooding due to a projected rainfall increase in rain-dominated catchments (e.g., humid Asia) where short-term extreme precipitation and long-term precipitation are both projected to increase (e.g., Asokan and Dutta, 2008; Dairaku et al., 2008; Hirabayashi et al., 2008b).

In summary it is *more likely than not* that anthropogenic forcing leading to enhanced greenhouse gas concentrations has affected floods because they have detectably influenced components of the hydrological cycle such as mean precipitation (Zhang et al., 2007a), heavy precipitation (see Section 3.3.2), and snowpack (Barnett et al., 2008). Floods are also projected to change in the future due to anthropogenic warming (see Section 3.5.2.3), but the magnitude and even the sign of this anthropogenic influence have yet not been detected/attributed in scientific literature, and the exact causes for regional changes in floods cannot be clearly ascertained. It is *likely* that anthropogenic influence has resulted in earlier spring flood peaks in snow-melting rivers; the observed earlier spring runoff is consistent with expected change under anthropogenic forcing. It should be noted that these two assessments are based on expert judgement rather than a formal model-based attribution study, although Pall et al., (2010) do provide more direct evidence of an anthropogenic influence on a specific extreme flood event.

3.5.2.3. Projected Changes and Uncertainties

The number of studies that showed the projection of flood changes in rivers especially at a regional or a continental scale was limited when AR4 was published. A rare example was Milly et al., (2002) who, using monthly river discharge calculated from climate model outputs, demonstrated the changes (mostly increases) in 'large' floods at selected extratropical river basins larger than 20,000km^2.

The number of studies is still limited. Recently, a few studies for Europe (Lehner et al., 2006; Dankers and Feyen, 2008, 2009) and a study for the globe (Hirabayashi et al., 2008b) have demonstrated changes in the frequency and/or magnitude of floods in the 21st century at a large scale using daily river discharge calculated from RCM or GCM outputs and hydrological models at a regional or a continental scale. For Europe, most notable changes are projected to occur in northern and northeastern Europe in the late 21st century, but the results are varied. Three studies (Dankers and Feyen, 2008; Hirabayashi et al., 2008b; Dankers and Feyen, 2009) show a decrease in the probability of extreme floods, that generally corresponds to lower flood peaks, in northern and northeastern Europe because of a shorter snow season, while one study (Lehner et al., 2006) shows an increase in floods in the same region. Changes in floods in central and western Europe are less prominent and with not much consistency seen between the four studies. For other parts of the world, Hirabayashi et al., (2008b) show an increase in the risk of floods in most humid Asian monsoon regions, tropical Africa and tropical South America, which were implied in an earlier study (Manabe et al., 2004) that used annual mean runoff changes obtained from a coarse resolution GCM. This projected change was also implied in earlier studies by the changes in precipitation in monsoon seasons (e.g., Palmer and Räisänen, 2002).

Lehner et al., (2006) and Hirabayashi et al., (2008b) both showed the geographical distribution of changes in hydrological drought in a future warmer climate as well as the changes in floods. From this it is possible to identify regions which are projected to experience changes in hydrological floods and droughts. However, the results for Europe are not consistent between these two studies. Most of south and southeast Asia, tropical South America and Sahel are projected to suffer both from hydrological floods and droughts, but this result does not have high reliability because only one model was used (Hirabayashi et al., 2008b).

Projections of flood changes at a catchment/river-basin scale are also not abundant in the scientific literature. Several studies have been undertaken for UK catchments (Cameron, 2006; Kay et al., 2009; Prudhomme and Davies, 2009) and catchments in continental Europe and North America (Graham et al., 2007; Thodsen, 2007; Leander et al., 2008; Raff et al., 2009; van Pelt et al., 2009). However, projections for catchments in other regions like Asia (Asokan and Dutta, 2008; Dairaku et al., 2008), the Middle East (Fujihara et al., 2008), Africa and South America are very rare. Most projections for rain-dominated catchments are carried out because rainfall intensification, which is anticipated to cause more or more severe floods, is projected by climate models in regions where those catchments are located. Flood probability is generally projected to increase in such catchments, but uncertainty is still large in the changes in the magnitude and frequency of floods (Cameron, 2006; Kay et al., 2009). Earlier spring flooding is projected in snow-dominated catchments, but the change in the magnitude of spring flood also varies between projections.

It has been recently recognized that the choice of GCMs is the largest source of uncertainties in hydrological projections, and uncertainties from downscaling methods are of secondary importance (Graham et al., 2007; Leander et al., 2008; Kay et al., 2009; Prudhomme and Davies, 2009), although, in general, hydrological-model projections require downscaling and bias-correction of GCM outputs (e.g., precipitation and temperature). The choice of hydrological models is also of secondary importance (Kay et al., 2009). Nevertheless, uncertainty analysis in the hydrological projections is still in its infancy, and the results may depend on the selected region/catchment, the selected downscaling and bias-correction methods, and the selected hydrological models (Wilby et al., 2008). For example, the above mentioned inconsistency between the projections of flood changes in snow-dominated regions in Europe (Lehner et al., 2006; Dankers and Feyen, 2008; Hirabayashi et al., 2008b; Dankers and Feyen, 2009) has been considered to be primarily due to differences in the downscaling and bias-correction methods applied in the different studies (Dankers and Feyen, 2009). Downscaling and bias-correction are also a major source of uncertainty in rain-dominated catchments (van Pelt et al., 2009).

In summary, the number of projections on flood changes is still limited at a regional and continental scale, and those projections often show some degree of uncertainty. Projections at a catchment/river-basin scale are also not abundant in the peer-reviewed scientific literature. In particular, projections for catchments except for Europe and North America are very rare. In addition, considerable uncertainty has remained in the projections of flood changes, especially regarding their magnitude and frequency. The exception is the robust projection of the earlier shift of spring peak discharge in snow-dominated regions. Therefore, it is currently difficult to make a statement on the confidence/likelihood of flood change projections due to anthropogenically induced climate change, except for the robustly projected earlier shift of spring floods (*likely*), because of insufficient reliability of climate models and downscaling methods.

3.5.3. Extreme Sea Levels

Extreme sea levels are caused by severe storms such as tropical or extratropical cyclones. The associated falling atmospheric pressure and strong winds can produce storm surges at the coast, which may be further elevated by coastal wave breaking which causes an onshore flux of momentum known as wave setup. Changes in extreme sea level may arise from changes in atmospheric storminess, (see sections 3.4.4 and 3.4.5) and will also occur as a result of mean sea level rise.

3.5.3.1. Observed Changes

The AR4 reported with high confidence that the rate of observed sea level rise increased from the 19th to the 20th century (Bindoff et al., 2007). It also reported that the global mean sea level rose at an average rate of 1.8 [1.3 to 2.3] mm yr^{-1} over 1961 to 2003 and at a rate of 3.1 [2.4 to 3.8] mm yr^{-1} over 1993 to 2003. Whether the faster rate of increase during the latter period reflected decadal variability or an increase in the longer term trend was not clear. However there is increasing evidence that the contribution to sea level due to mass loss from Greenland and Antarctica is accelerating (Velicogna, 2009). The total 20th-century rise was estimated to be 0.17 [0.12 to 0.22] m (Bindoff et al., 2007).

The AR4 reported that the rise in mean sea level and variations in regional climate led to a likely increase in trend of extreme high water worldwide in the late 20th century (Bindoff et al., 2007) and that it was *more likely than not* that humans contributed to the trend in extreme high sea levels (IPCC, 2007a). This conclusion was based on a number of studies of sea level extremes, the most geographically comprehensive being that of Woodworth and Blackman (2004) who found that increases in 99th percentile sea levels at 141 tide gauges across the globe since 1975 were mostly attributable to the trend in mean sea level. Since the AR4, several new studies have been undertaken. These studies provide further evidence that changes in extremes are related to trends in mean sea level and modes of variability in the regional climate. The overall assessment of these studies confirms but does not change the AR4 assessment.

Several studies since the AR4 report that trends in extreme sea level are broadly consistent with changes in mean sea level. Menendez and Woodworth (2010), using sea level records from 258 tide gauges across the globe, confirms the earlier conclusions of Woodworth and Blackman (2004) that there has been a trend in extreme sea levels globally, which has been more pronounced since the 1970’s, and this trend is consistent with trends in mean sea level. Marcos et al., (2009) found changes in extreme sea levels in 73 tide gauges in the Mediterranean and the southern Atlantic Ocean since 1940 were consistent with mean sea level changes. Haigh et al., (2010), using an expanded and spatially more comprehensive sea level data set for the English Channel, concluded that extreme sea levels increased at all of the 18 sites, but at rates not statistically different from mean sea level rise.

A number of studies also highlight the additional influence of climate variability on extreme sea level trends. Menendez and Woodworth (2010) report that ENSO has a large influence on interannual variations in extreme sea levels since the 1970s throughout the Pacific Ocean and the monsoon regions. In southern Europe, Marcos et al., (2009) find that in addition to mean sea level changes, changes in extremes are also significantly negatively correlated with the NAO. A more localised study in the Camargue (Rhone Delta) region of southern France by Ullmann et al., (2007) concluded that maximum annual sea levels had risen twice as fast as mean sea level during the 20th century. Subsequent studies that have examined the role of changes in weather conditions in extreme sea level trends in this region find that while most extremes occur during particular weather patterns that are associated with the negative NAO phase (Ullmann and Moron, 2008) the increased frequency of sea surges in this region in the latter part of the 20th Century is due to an increase in southerly winds associated with a general rise in sea level pressure over central Europe over this period (Ullmann et al., 2008).

Abeysirigunawardena and Walker (2008) report that sea level trends from two tide gauge records over the period from 1939 to 2003 in Prince Rupert Sound on the north coast of British Columbia were twice that of mean sea level rise, the additional contribution being due to the strong positive PDO phase which has lasted since the mid-1970s. Cayan et al., (2008) reported increases in the frequency of exceedance of the 99.99th percentile sea level of 20-fold at San Francisco since 1915 and 30-fold at La Jolla since 1933 and also note that positive sea level anomalies of 10 to 20 cm often persisted for several months during El Niño events, which causes an increase in storm surge peaks.

In the Southern Hemisphere, Church et al., (2006b) examined changes in extreme sea levels before and after 1950 in two tide gauge records of approximately 100 years at Fort Denison and Fremantle on the east and west coasts of Australia respectively. At both locations a stronger positive trend is found in the 99.99 percentile sea level (the sea level which is exceeded by 0.01 per cent of the observations) than the median sea level, suggesting that in addition to mean sea level rise other modes of variability or climate change are contributing to the extremes. At Mar del Plata, Argentina, Fiore et al., (2009) note an increase in the number and duration of positive storm surges in the decade 1996 to 2005 compared to previous decades. However the relative contributions of mean sea level rise and changes in wind climatology due to a southward shift in the South Atlantic high are not quantified.

3.5.3.2. Causes Behind the Changes

Studies since the AR4 conclude that trends in extreme sea level are generally consistent with changes in mean sea level (e.g., Marcos et al., 2009; Haigh et al., 2010; Menendez and Woodworth, 2010) although some studies note that the trends in extremes are larger than the observed trend in mean sea levels (e.g., Church et al., 2006b; Ullmann et al., 2007; Abeysirigunawardena and Walker, 2008). Several studies also find that extreme sea levels are influenced by modes of climate variability (e.g., Abeysirigunawardena and Walker, 2008; Marcos et al., 2009; Menendez and Woodworth, 2010). These studies support the conclusions from the AR4 that increases in extremes are related to trends in mean sea level and modes of variability in the regional climate.

3.5.3.3. Projected Changes and Uncertainties

The AR4 (Meehl et al., 2007b) projected sea level rise for 2090–2099 relative to 1980–1999. The estimated rise from ocean thermal expansion, glaciers and ice caps, and modelled ice sheet contributions is projected to be 18–59 cm with a 90% confidence range. An additional allowance to the sea level rise projections was made for a possible rapid dynamic response of the Greenland and West Antarctic ice sheets, which could result in an accelerating contribution to sea level rise. This was estimated to be 10–20 cm of sea level rise using a simple linear relationship with projected temperature. Because of insufficient understanding of the dynamic response of ice sheets, Meehl et al., (2007b) also noted that a larger contribution could not be ruled out.

The AR4 (Christensen et al., 2007) suggests that the dynamical downscaling step in providing forcing for regional surge (and correspondingly wave) models is robust (i.e., does not add to the uncertainty), but that the general low level of confidence in projected circulation changes from GCMs implies a substantial uncertainty in surge (and ocean wave) projections.

New studies carried out over the northern European region since the AR4, whose focus is on changes to storminess, have attempted to address uncertainties in extreme sea level changes using a large ensemble of simulations (e.g., Sterl et al., 2009) or address uncertainties due to scale issues by downscaling in RCM simulations (e.g., Wang et al., 2008), or both (Debernard and Roed, 2008). These studies project increases in storm surge height along the eastern North Sea coast, the Irish west coast, and the Irish Sea, consistent with earlier studies. However, the small number of studies and limited regional coverage of such studies do not provide a basis to change the AR4 assessment of projected extreme sea level changes as the ensemble of model simulations is still small and the results show considerable regional variations. Other studies have focused more on an exploration of scenarios of future changes in mean sea level in relation to changes in meteorological forcing and conclude that mean sea level rise will be the main factor in extreme sea level changes in the future (e.g., Harper et al., 2009; McInnes et al., 2009b; Brown et al., 2010).

Debernard and Roed (2008) investigated the effect of changing meteorological conditions on storm surges over Europe in several models under A2 and B2 greenhouse gas scenarios. Despite large inter-model differences, statistically significant differences between 2071-2100 and 1961-1990 include decreases in storm surge south of Iceland, and an 8-10% increase in the 99th percentile storm surge heights along the coastlines of the eastern North Sea and northwest of the British Isles. The changes relate mainly to changes in the winter season in the climate models.

Wang et al., (2008) examined storm surges in Irish coastal seas in 30-year time slices for the periods 1961-1990 and 2031-2060 from an A1B simulation downscaled by the Rossby Centre Regional Atmosphere model. The results show an increase in storm surge events around Irish coastal areas in the future time-slice, except along the south Irish coast. There is also a significant increase in the height of the extreme surges along the west and east Irish coasts, with most of the extreme surges occurring in wintertime.

Sterl et al., (2009) used a 17-member ensemble of A1B simulations from 1950 to 2100 to examine future changes to the 10000-year sea level height along the Dutch coastline. By concatenating the output from the 17 ensemble members over the model periods 1950-2000 and 2050-2100 into a single longer time series for each time slice, return periods were estimated with narrower uncertainties and no statistically significant change in the 10000 year return values of surge heights along the Dutch coastline were found during the 21st century. This was attributed to the fact that wind speed changes in the future climate were not associated with the surge-generating northerlies but rather southwesterlies. However, they stress that the result is based only on output from one climate model.

Other studies have undertaken a sensitivity approach and compared the relative impact on extreme sea levels of meteorological changes and mean sea level rise by perturbing the meteorological conditions which caused current climate storm surges. Over southeastern Australia, McInnes et al., (2009b) found that a 10% increase in wind speeds, consistent with the upper end of the range under an A1FI scenario from a multi-model ensemble (note that the lower end of this range was for wind decrease) produced an increase in sea levels that were 20 to 35% of that due to the upper end of the A1FI sea level rise scenario for 2070. Brown et al., (2010) investigated the relative impact of sea level rise and wind speed change on an extreme storm surge in the eastern Irish Sea. Both studies conclude that sea level rise has the greater potential to increase extreme sea levels in the future.

The degree to which climate models (GCM or RCM) have sufficient resolution and/or internal physics to realistically capture the meteorological forcing responsible for storm surges will be regionally dependant. For example current

GCMs are unable to realistically represent tropical cyclones. This has led to the use of alternative approaches for investigating the impact of climate change on storm surges in tropical Australia. For example, methods have been used that rely on the generation of synthetic cyclones whose characteristics are perturbed to represent projected future cyclone characteristics in this region (e.g., McInnes et al., 2003). Recent studies on the tropical east coast of Australia reported in Harper et al., (2009) that employ these approaches show a relatively small impact of a 10% increase in tropical cyclone intensity on the 1 in 100 year storm tide, with mean sea level rise producing the larger contribution to changes in future sea level extremes.

3.5.4. Waves

Severe waves can damage and destroy coastal infrastructure and threaten the safety of coastal inhabitants. Waves play a significant role in shaping a coastline by transporting energy from remote areas of the ocean to the coast. Energy dissipation via wave breaking contributes to beach erosion, longshore currents, and elevated coastal sea levels through wave set-up and wave run-up. Properties of waves that influence these processes include wave height, direction, and period although to date studies of past and future wave climate changes have tended to focus on wave height parameters such as ‘significant wave height’ (SWH), which is the height from trough to crest of the highest one third of waves.

3.5.4.1. Observed Changes

The AR4 reported statistically significant positive trends in SWH over most of the mid-latitudinal North Atlantic and North Pacific, as well as in the western subtropical South Atlantic, the eastern equatorial Indian Ocean and the East China and South China Sea (Trenberth et al., 2007), based on trends in SWH from voluntary observing ship data (VOS) (e.g., Gulev and Grigorieva, 2004).

Several studies that address trends in extreme wave conditions have been completed since the AR4 and the new studies generally provide more evidence for the previously reported trends in the north Atlantic and north Pacific (Weisse and Günther, 2007; Wang et al., 2009b). Positive trends in wave height are also found along the U.S. east and west coasts (Allan and Komar, 2006; Komar and Allan, 2008; Menendez et al., 2008), and the southern ocean (Hemer et al., 2010). Wave climate studies on the U.S. west coast have found a positive correlation between wave height and El Niño (Allan and Komar, 2006; Adams et al., 2008; Menendez et al., 2008). However, the different sources of wave information (i.e., direct measurements, satellite observations and reanalysis products) and the focus of the studies on different geographical regions contribute to uncertainties for observed wave climate changes. Until more studies are completed and the relationship between different wave data products are better understood, a stronger assessment will not be possible.

Generally confirming previously reported regional trends, Wang et al., (2009b) found that wave heights increased in the boreal winter over the past half century in the high latitudes of the Northern Hemisphere (especially the northeast Atlantic), and decreased in more southerly northern latitudes based on ERA-40 reanalysis products. Weisse and Günther (2007) analysed extreme wave conditions from a regional North Sea hindcast (1958–2002) and found a positive trend in severe wave heights in the southern North Sea from 1958 to the early 1990s, followed by a declining trend since. Along the UK North Sea coast, a reduction in severe wave conditions was observed over much of the hindcast period.

However trends at particular locations may be influenced by local factors. For example, Suursaar and Kullas (2009) reported a slight decreasing trend in mean SWHs from 1966–2006, while the frequency and intensity of high wave events showed rising trends. These changes were associated with a decrease in local average wind speed, but an intensification of the westerly winds and storm events.

On the North American Atlantic coast, Komar and Allan (2008) found a statistically significant increasing trend in wave heights of 0.059 m/yr at Charleston, South Carolina during the summer months since the 1970s with lower but statistically significant trends at wave buoys further north. The positive trends are associated with an increase in intensity and frequency of hurricanes over the period. In contrast, the waves measured during the winter, generated by extratropical storms, were not found to have experienced a statistically significant change.

Positive trends in wave height were also found by Allan and Komar (2006) and Menendez et al., (2008) along the U.S. west coast based on 25 and 22 years of wave records respectively. Both studies find a strong relationship between wave height and El Niño which is also found by Adams et al., (2008) further south over the Southern California Bight using a 50 year wave hindcast. Similarly, over the western north Pacific, Sasaki & Toshiyuki (2007) find that the 90th percentile of the summertime SWH which is associated with typhoons in eastern Asia was strongly correlated with cyclonic circulation in the western North Pacific and warm SST anomalies in the Nino 3.4 region.

Hemer et al., (2010) find a positive trend in wave height mainly confined to the region south of 45°S over the period 1998–2000 relative to 1993–1996 based on satellite data whereas extensive positive trends are seen over much of the Southern Hemisphere in the ERA-40 waves reanalysis over the same period.

3.5.4.2. *Causes Behind the Changes*

Wave climate studies point to strong links in wave climate and natural modes of climate variability (e.g., Allan and Komar, 2006; Adams et al., 2008). However, only one study (Wang et al., 2009c) detects a link between external forcing (i.e., anthropogenic forcing due to greenhouse gases and aerosols, and natural forcing due to solar and volcanic forcing) and an increase in wave heights in the boreal winter over the past half century in the high-latitudes of the Northern Hemisphere (especially the northeast North Atlantic), and a decrease in more southerly northern latitudes.

3.5.4.3. *Projected Changes and Uncertainties*

The AR4 projected a general tendency for more intense but fewer storms outside the tropics, with a tendency towards higher ocean waves in several regions (Meehl et al., 2007b), and increases in wave height were projected for most of mid-latitude areas analysed, including the north seas (Christensen et al., 2007) but with low confidence due to the low confidence in projected changes in mid-latitude storm tracks and intensities.

Since the AR4, there have been several studies that have developed regional (Andrade et al., 2007; Leake et al., 2007; Debernard and Roed, 2008; Grabemann and Weisse, 2008; Lionello et al., 2008; Hemer et al., 2009) and global (Mori et al., 2009) wave climate projections. Forcing conditions are typically obtained for a few selected emission scenarios (typically B2 and A2, representing low-high ranges) from a single or at most three coarse resolution GCMs. While these additional downscaling studies in more climate model simulations provide further evidence for projected increases in wave height in some regions such as the eastern North Sea coast, they do not change the low level of confidence in the findings due to the small number of climate models upon which the studies are based.

Wang et al., (2009a) compared dynamical and statistical downscaling methods for estimating seasonal statistics of SWH. They found that dynamical downscaling approaches, which have been common practice over the past few years, have not adequately resolved the issue of model variability biases. They found that the dynamical approach for downscaling was poorer than the statistical approach in terms of reproducing the observed climate and interannual variability of the wave heights. They also reported a better reproduction of the interannual variability of seasonal statistics (including extremes) when using high temporal resolution forcing data, stressing the importance of higher resolution data from climate model outputs.

Mori et al., (2009) forced a global wave model with the 20km high-resolution atmospheric MRI/JMA GCM, for three time slices (1979-2004, 2015-2031, and 2075-2100) following the A1B scenario. They project higher maximum wave heights in mid and high-latitudes. Lower mean wave heights are projected for mid-latitudes. The projected changes are qualitatively consistent with global wave projections carried out by Wang and Swail (2006b) and are also consistent with patterns of extreme wind change reported in Gasteneau and Soden (2009) and Figure 3.10.

Debernard and Roed (2008) examined wave climate changes around Europe in several models under A2, B2 and A1B greenhouse gas scenarios. They project a 6% decrease in 99th percentile SWH from 1960-1990 to 2070-2100 southwest of Iceland. A 6-8% increase in the annual 99th percentile SWH is projected along the eastern coast of the North Sea and the Skagerrak. An increase in the annual 99th percentile SWH is also projected along the west coast of the British Isles, was found to be associated to a change in the winter storm track.

Grabemann and Weisse (2008) used a regional wave model to downscale two GCMs under A2 and B2 emission scenarios. An increase of up to 18% from the ensemble mean long-term 99th percentile SWH is projected for 2071-2100 compared to 1961-1990 in the North Sea, except for off the English coast. This is in contrast to Leake et al., (2007) who downscaled the same GCM for the same emission scenarios, using a different RCM and found positive changes in high percentile wave heights offshore of the East Anglia coastline. Lionello et al., (2008) project mostly decreases in extreme SWH for 2071-2100 over the Mediterranean Sea with larger decreases for the A2 scenario using winds downscaled from a GCM.

3.5.5. *Coastal Impacts*

Two classes of coastal hazard that are particularly significant in the context of disaster management are coastal inundation and shoreline stability. The frequency and severity of such events will be affected by climate change through rising sea levels and changes in extreme events. Figure 3.12 illustrates the interactions between various forms of climate forcing and coastal impacts. Several additional contributions to coastal impacts are also acknowledged such as extreme rainfall and runoff in coastal catchments which may contribute to coastal flooding. Multiple effects may occur on some coastlines as increasing ocean temperatures reduce natural barriers that protect against the erosive forces of waves. Examples include the melting of sea ice and permafrost in high latitudes (see Section 3.5.6) and the degradation of coral reefs through increased coral bleaching in the tropics. Wind can also have a direct erosive effect on coastlines, and coastal exposure to this influence is exacerbated during periods of extreme low coastal sea levels such as negative surges.

INSERT FIGURE 3.12 HERE

Figure 3.12: Relationships between climate, weather phenomena and physical impacts in the coastal zone.

Coastal inundation occurs during periods of extreme sea levels due to storm surges and high waves, particularly when combined with high tides. While tropical and extra-tropical cyclones are the most common causes of sea level extremes, other weather events can cause sea level extremes. For example, Green et al., (2009) reports an example of extreme sea levels and inundation affecting the low-lying Torres Strait Islands between the Cape Yorke Peninsula of Australia and Papua New Guinea as a result of persistent southeasterly winds from an anti-cyclone to the south. On the southeastern coast of Australia, frontal systems are a major cause of storm surges (McInnes et al., 2009b). In many parts of the world sea levels are also influenced by modes of variability such as ENSO. In the western equatorial Pacific, sea levels can fluctuate up to half a metre from one phase of ENSO to the other (Church et al., 2006a) and in combination with extremes of the tidal cycle, can cause extensive inundation in low-lying atoll nations in the absence of extreme weather events.

Extreme sea levels and high waves may lead to significant erosion of the coastline. In general, changes in shoreline position can arise from the combined effects of various factors such as:

1. A gradual rise in mean sea level, which causes a landward recession of coastlines that are made up of erodible materials.
2. Changes in the frequency or severity of transient storm erosion events (Zhang et al., 2004a).
3. Changes in sediment supply to the coast (Stive et al., 2003; Nicholls et al., 2007).
4. Changes in wave direction or period through sea level rise which alters wave refraction or climate variability which can cause realignment of shorelines (Ranasinghe et al., 2004; Bryan et al., 2008).
5. The loss of natural protective structures such as, coral reefs (e.g., Sheppard et al., 2005; Gravelle and Mimura, 2008) or in polar regions the melting of permafrost or sea ice which exposes soft shores to the buffering effects of waves and severe storms (Manson and Solomon, 2007).

The degree to which the processes described above will impact the coast are also a function of the coastal attributes themselves. For example, coastal elevation relative to sea level determines the severity and frequency of coastal inundation. In this regard, vertical movement of the land adjacent to the coast is also an important consideration (Haigh et al., 2009). Some coastal regions may be rising due to post-glacial rebound or slumping due to aquifer drawdown, the latter of which has anthropogenic origins. Similarly, the erodability of the coast is dependent on its particular physical (e.g., shoreline slope) and geomorphological attributes.

The susceptibility of a coastal region to erosion and inundation may be inferred from the following broad coastal characteristics, e.g., Nicholls et al., (2007):

- Beaches, rocky shorelines and cliffed coasts
- Deltas
- Estuaries and lagoons
- Mangroves, saltmarshes and sea grasses
- Coral reefs

Deltas are low-lying and hence generally prone to inundation, beaches are comprised of loose particles and therefore erodible. However, the degree to which these systems may be impacted by erosion and inundation may also be influenced by other factors which may affect disaster responses. For example, depleted mangrove forests or the degradation of coral reefs may reduce the buffering effect from high waves during severe storms, (e.g., Gravelle and Mimura, 2008); there may be a loss of ecosystem services brought about by saltwater contamination of already limited freshwater reserves due to rising sea levels and these amplify the risks of climate change (McGranahan et al., 2007), and also reduce the resilience of coastal settlements to disasters.

3.5.5.1. Observed Changes

The AR4 (Nicholls et al., 2007) reported that coasts are experiencing the adverse consequences of hazards such as increased coastal inundation, erosion and ecosystem losses. Since the AR4 a small number of additional studies that address shoreline evolution have been completed which do not change the AR4 assessment. The studies highlight the difficult task of clearly identifying a response due to climate change against a background of often large change brought about by other anthropogenic drivers, and of natural ongoing evolution and changes that occur due to natural climate variability such as ENSO (e.g., Ranasinghe et al., 2004; Allan and Komar, 2006). The scarcity and fragmentary nature of data sets as noted in Defeo et al., (2009) contributes to this problem.

In the Caribbean, the beach profiles at 200 sites across 113 beaches and eight islands were monitored on a three-monthly basis from 1985 to 2000 (Cambers, 2009). Most beaches surveyed were found to be eroding, with faster rates of erosion generally found on islands that had been impacted by a higher number of hurricanes. The relative importance of anthropogenic factors, climate variability and climate change on the eroding trends could not be separated quantitatively.

Church et al., (2008) report that despite the positive trend in sea levels during the 20th century, Australia has generally been free of chronic coastal erosion problems. Where coastal erosion has been observed, it has not been possible to unambiguously attribute an erosion signal to sea level rise, in the presence of other anthropogenic activities.

A quantitative analysis of physical changes in 27 atoll islands across three central Pacific islands (Tuvalu, Kiribati and Federated States of Micronesia) over a 19 to 61 year period found 86% of islands remained stable or increased in area (43%) over the timeframe of analysis (Webb and Kench, 2010). Largest decadal rates of increase in island area range between 0.1 to 5.6 hectares. Only 14% of study islands exhibited a net reduction in island area. Despite small net changes in area, islands exhibited larger gross changes which represented a net lagoonward migration of islands in 65% of cases.

Chust et al., (2009) evaluate the relative contribution of local anthropogenic (non-climate change related) and sea level rise impacts on the coastal morphology and habitats in the Gipuzkoan littoral zone (Basque coast, northern Spain) for the period 1954–2004. They found that the impact from local anthropogenic influences was about an order of magnitude greater than that due to sea level rise over this period.

3.5.5.2. Causes Behind the Changes

Assessments of coastal erosion that have been undertaken since the AR4 in the Caribbean (Cambers, 2009), Pacific (Webb and Kench, 2010), Australia (Church et al., 2008) and northern Spain (Chust et al., 2009) have tended to highlight the large natural and/or non-climatic anthropogenic contribution to current shoreline trends which prevent the identification of a climate change signal. The small number of studies that have been completed since the AR4 are either unable to attribute the coastline changes seen to different causes in a quantitative way or else find strong evidence for non-climatic causes that are natural and/or anthropogenic. This is consistent with the AR4, which stated with very high confidence that the impact of climate change on coasts is exacerbated by increasing human-induced pressures.

3.5.5.3. Projected Changes

The AR4 reported with very high confidence that coasts will be exposed to increasing risks, including coastal erosion, over coming decades due to climate change and sea level rise both of which will be exacerbated by increasing human-induced pressures (Nicholls et al., 2007). However it was also noted that since coasts are dynamic systems, adapting to climate change required insight into processes at decadal to century scales, at which understanding is least developed.

Since the AR4 several new studies have been completed that build understanding of how climate change will impact the coastlines in the future. These include new nationwide coastal assessments in several European countries and Australia that qualitatively assess coastal vulnerability based on the physical and geomorphological attributes of the coast and known existing vulnerabilities (e.g., Nicholls and de la Vega-Leinert, 2008). There have been several studies that model and map inundation from future scenarios of extreme sea level (e.g., Bernier et al., 2007; McInnes et al., 2009a), new studies that employ probabilistic frameworks to incorporate future climate uncertainty in impact studies which show promise for managing the large uncertainties in climate change projections (e.g., Purvis et al., 2008; Hunter, 2010) and studies that investigate the relative impact of wave climate and mean sea level changes on shoreline stability (Andrade et al., 2008; Coelho et al., 2009).

SURVAS (Synthesis and Upscaling of sea level Rise Vulnerability Assessment Studies) provides a qualitative assessment of vulnerability to climate change across Europe (Nicholls and de la Vega-Leinert, 2008). Aunan and Romstad (2008) report that Norway’s generally steep and resistant coastlines contribute to a low physical susceptibility to accelerated sea level rise. Nicholls and de la Vega-Leinert (2008) report for Great Britain that large parts of the coasts (including England, Wales, and Scotland) already experience problems, including sediment starvation and erosion, loss/degradation of coastal ecosystems, and significant exposure to coastal flooding. Lagoons, river deltas and estuaries are assessed as being particularly vulnerable in Poland (Pruszak and Zawadzka, 2008). In Estonia, Kont et al., (2008) report increased beach erosion, which is believed to be the result of recent increased storminess in the eastern Baltic Sea, combined with a decline in sea-ice cover during the winter. Sterr (2008) reports for Germany that there is a high level of reliance on hard coastal protection against extreme sea level hazards which will increase ecological vulnerability over time. A coastal vulnerability assessment for Australia (Department of Climate Change, 2009), identifies four broad coastal regions based on geomorphology, sediment type and tide and wave characteristics. The tropical northwestern coastline is expected to be most sensitive to changes in tropical cyclone behaviour while health of the coral reefs may also influence the tropical eastern coastline. The midlatitude southern and eastern coastlines are expected to be most sensitive to changes in mean sea level, wave climate and changes in storminess.

There have also been several studies that have developed methods for investigating the impact of inundation on the natural environment. Bernier et al., (2007) evaluated species vulnerability to inundation from future sea level rise using seasonal return periods of high water. McInnes et al., (2009a) developed spatial maps of stormtide and used high resolution LiDAR data to investigate exposure of coastal land to inundation under future sea level and wind speed scenarios along the Victorian coastline of southeast Australia. Probabilistic approaches have also been used to evaluate extreme sea level exceedance under uncertain future sea level rise scenarios. In the approach described in Purvis et al., (2008), a plausible probability distribution is applied to the range of future sea level rise estimates and Monte-Carlo sampling used to apply the sea level change to a 2D coastal inundation model. It is shown that evaluating the possible flood related losses (in monetary terms) in this framework is able to represent spatially the higher losses associated with the low frequency but high impact events compared with considering only a single midrange scenario. Hunter (2010) presents a method of combining sea-level extremes evaluated from observations with projections of sea level rise to 2100 to evaluate the probabilities of extreme events being exceeded over different future time horizons.

For the Portuguese coast, two studies report that projected changes in wave climate are likely to cause increased erosion in the future. Andrade et al., (2008) find that projected future climate in the HadCM3 model will not affect wave height along this coastline but the rotation in wave direction will increase the net littoral drift and the erosional response. On the basis of modelling various climate change scenarios for the next 25 years, Coelho et al., (2009) also find that the effects of sea level rise are less important than changes in wave action along a stretch of the Portuguese coast.

There have also been further developments in coastal erosion modelling within probabilistic frameworks that can take into account storm duration and sequencing (i.e., the compound effects on beach erosion that result from storms that occur in short succession) (Callaghan et al., 2008). Such methods have not as yet been applied in a climate change context.

3.5.6. Glaciers and Mountain Impacts

The steep topography of high-mountains is prone to gravity-driven mass movements such as landslides, avalanches, and floods that can lead to disasters.

3.5.6.1. Observed Changes

High-mountain environments are characterized by fast changes especially in recent decades with unprecedented retreat of glaciers all over the world (Paul et al., 2004; Kaser et al., 2006; Larsen et al., 2007; Rosenzweig et al., 2007). Conditions beyond historical experience have arisen at the beginning of the 21st century (Haeberli and Hohmann, 2008).

Most of the observed changes in glacier, permafrost, and snow related events are caused by temperature increases (Lemke et al., 2007). While an increase in air temperature can result in an increase of firn and ice temperature, the more visible effect of warming is the impact on glacier geometry (thickness, length, area, volume). Glacier geometry changes are controlled by the mass balance and dynamics of a glacier.

Since their last maximum at the end of the Little Ice Age (~1850) glaciers are predominantly retreating, interrupted by short periods of advance during the 20th century (Oerlemans, 2005). The mass loss of glaciers has clearly been increased towards the more recent years, with thickness losses in water equivalent ranging from 0.14 m from 1976 to 1985, to 0.25 m from 1986 to 1995, to 0.58 m during the period 1996–2005 (Zemp et al., 2007). Glacier length is also decreasing. The magnitude of downwasting at glacier terminal areas has been reported as up to 4–5 m/yr between 1985 and 2000 for the Swiss Alps (Paul and Haeberli, 2008), and up to 5–10 m/yr in southeast Alaska and British Columbia for about the last two decades of the 20th century (Larsen et al., 2007; Schiefer et al., 2007).

Evidence of mountain permafrost degradation and slope destabilization comes from a number of recent slope failures in permafrost areas, including a magnitude scale from block and rock fall to rock avalanches (volumes of ~10^2 to 10^7 m^3), observed in the European Alps (Gruber and Haeberli, 2007; Huggel, 2009) and also in other mountain regions (Niu et al., 2005; Allen et al., 2010). Examples are the 1997 Brenva rock avalanche in the Mont Blanc region (Barla et al., 2000), the 2004 Thurwieser rock avalanche, Italy (Sosio et al., 2008), rock slides from Dents du Midi and Dents Blanches, Switzerland, in 2006, or from Monte Rosa, Italy, in 2007 (Huggel, 2009; Fischer et al., 2010a), with volumes of a few millions of cubic meters. Very large rock and ice avalanches with volumes of 50 to over 100 million m^3 have occurred in the 2002 Caucasus Kolka avalanche (Haeberli et al., 2004; Kotlyakov et al., 2004; Huggel et al., 2005) and in 2005, Mt. Steller, south-central Alaska (Huggel et al., 2008).

Quantification of trends in occurrence of such events is difficult due to uncertainty in documentation, despite a generally increasing level of documentation in recent years. Nevertheless, there is an apparent increase of large rock slides during the past two decades, and especially during the first years of the 21st century the frequency has increased in the European Alps and the Southern Alps of New Zealand (Allen et al., 2010; Fischer et al., 2010b), in parallel with strong temperature increases, glacier shrinkage, and permafrost degradation.

3.5.6.2. Causes Behind the Changes

Hazards and extreme events in high mountains occur due to cumulative changes in glacier and permafrost, or are of a stochastic nature. Glacier lake outburst floods (GLOFs) are typically a result of cumulative developments, and occur (i) only once (e.g., full-breach failure of moraine-dammed lakes), (ii) for the first time (e.g., new formation and outburst of glacial lakes), and/or (iii) repeatedly (e.g., ice-dammed lakes with drainage cycles, or ice fall) (Clarke, 1982; Clague and Evans, 2000; Huggel et al., 2004; Dussaillant et al., 2010). In the past decades GLOFs have caused severe disasters in many high-mountain regions of the world (Rosenzweig et al., 2007), including the Andes (Reynolds et al., 1998; Carey, 2005; Hegglin and Huggel, 2008), the Caucasus and Central Asia (Narama et al., 2006; Aizen et al., 2007), the Himalayas (Vuichard and Zimmermann, 1987; Richardson and Reynolds, 2000; Xin et al., 2008; Bajracharya and Mool, 2009; Osti and Egashira, 2009), North America (Clague and Evans, 2000; Kershaw et al., 2005), and the European Alps (Haeberli, 1983; Haeberli et al., 2001). Due to the relatively rare occurrence of GLOFs, clear information on possible changes of occurrence of such extreme events on the regional or global level is lacking. For the Himalayas a small but not statistically significant increase of GLOF events was observed over the period 1940 to 2000 (Richardson and Reynolds, 2000).

Degradation of permafrost due to warming affects slope stability. However, monitoring of mountain permafrost temperatures has a short history with only about 20 years of data (Vonder Mühll et al., 1998; Niu et al., 2005; Harris et al., 2009) for gently sloped terrain, and less than 10 years for steep rock slopes (Gruber et al., 2004b). Any significant warming trend of bedrock permafrost cannot yet be derived from the small number of monitoring years, but the 2003 European summer heat wave (Section 3.3.1.1) has been associated with rapid thaw and extension of the active layer, and an increased number of predominantly small-scale rock fall events (Gruber et al., 2004a; Gruber and Haeberli, 2007).

Shallow landslides and debris flows generally follow a stochastic pattern as they are primarily triggered by precipitation. The spatial and temporal patterns of precipitation, the intensity, the duration of rainfall and the antecedent rainfall are all important for shallow landslides (Iverson, 2000; Wieczorek et al., 2005; Sidle and Ochiai, 2006). In some regions the influence of antecedent rainfall on landslide triggering is likely to dominate over rainfall intensity (Kim et al., 1991; Glade, 1998), although some uncertainty may be involved from temporally insufficient resolution of rainfall records. Landslides in temperate and tropical mountains usually are not temperature sensitive and can be more strongly influenced by human activities such as poor land-use practise, deforestation, overgrazing, etc.

For shallow landsliding and debris flows in high mountains, observations indicate that the initiation zones move upwards as glaciers retreat and new poorly consolidated sediment becomes exposed (Rickenmann and Zimmermann, 1993; Zimmermann and Haeberli, 1993; Haeberli and Beniston, 1998). Research has so far not provided any clear indications of change in the frequency of debris flows. In the Swiss Alps it was found that debris flow activity on a local site was higher during the 19th century than today (Stoffel et al., 2005) while in the French Alps no significant variation of debris flow frequency could be observed since the 1950s in high-mountain terrain above 2200 m a.s.l (Jomelli et al., 2004). Indirect climate effects such as increase of available sediment or changing seasonal snow patterns can also influence debris flow activity (Rebetez et al., 1997; Beniston, 2006). Statistics are not completely clear but there could be an increase of debris flow activity in alpine regions during the past decades due to extreme rainfall events, in combination with a snow fall line located at high elevation, contributing to enhanced liquid precipitation. The elevated activity of high-mountain landslide activity during the recent warming is consistent with findings on the occurrence of large events during the post-Ice Age and early Holocene (Holm et al., 2004; Prager et al., 2009).

Several events in the past decades have shown that particularly severe physical impacts can result from interacting and cascading processes. Typical processes are outburst floods of glacier lakes due to impact waves generated by failure of moraine slopes (Hubbard et al., 2005; Vilimek et al., 2005) or ice and rock avalanches (Clague and Evans, 2000). Very large rock-ice avalanches and debris flows, triggered by initial rock or ice failures (Huggel et al., 2005; Evans et al., 2009), or volcanic eruptions (Pierson et al., 1990) have killed hundreds to thousands of people during the 20th century. There is no indication so far as to whether such large events with cascading processes have increased during the past decades.

The initiation of shallow landslides and debris flows in cold regions and high mountains can be influenced by the thermal state (frozen vs. unfrozen conditions), and related hydraulic effects of scree slopes (Haeberli et al., 1990; Rickenmann and Zimmermann, 1993). Permafrost thawing and related depth increase of the active layer, together with incomplete thaw consolidation after melt, may increase both frequency and magnitude (higher potential erosion depth) of debris flows (Zimmermann et al., 1997; Rist and Phillips, 2005). On the other hand, permafrost at the base of the active layer also acts as a hydraulic barrier to groundwater percolation and can imply local saturation within the non-frozen debris. Snow cover distribution and melt can also have an important effect on debris flow activity by supplying additional liquid water for soil saturation favoring slope instabilities (Kim et al., 2004). The large debris flow events in the past 20 years, triggered by intensive rainfall and affecting extensive areas of the Alps, occurred in summer or fall and were typically characterized by a high elevation of the snow fall limit (Rickenmann and Zimmermann, 1993; Chiarle et al., 2007). Warming may directly influence the flow speed of frozen bodies of debris and rock such as rock glaciers. In recent years ground and remote sensing based monitoring has revealed remarkable acceleration of rock glaciers surface flow-speed of up to 4 m y^{-1}(Kääb et al., 2007; Roer et al., 2008). At some specific sites in the Alps, flow-speeds have occasionally reached up to 15 m y^{-1}, associated with slope instabilities (Delaloye et al., 2008). These phenomena have only recently been identified and could lead to large single events such as debris avalanches or alter the frequency and magnitude of debris flows.

Rock slope failure is often a result of slope steepening by glacial erosion and unloading or debuttressing due to glacier retreat (Augustinus, 1995), though it may take decades for a slope failure to occur due to glacier retreat. Recent rock slope failures, including the one in Grindelwald, Swiss Alps (Oppikofer et al., 2008), have confirmed the short response to glacier downwasting within a few decades or event shorter. 20th century warming may have reached some decameters depth on high steep slopes (Haeberli et al., 1997), and will continue to reach increasingly greater depths with future warming. Case studies of exceptionally warm periods of weeks to months duration indicate that both small-scale and large-scale slope failures can be triggered (Gruber et al., 2004a; Huggel, 2009; Fischer et al., 2010a).

Observed changes in physical impacts such as landslides, avalanches, and GLOFs that are primarily temperature driven and occur in cold and high mountain regions have *likely* been influenced by the anthropogenic greenhouse gas increase, since there is a direct physical link between warming and those changes, and the warming in those regions over the second half of the 20th century has been observed and attributed to anthropogenic influence. There is however a lack of evidence to assess any influence or lack of influence from anthropogenic warming on other observed physical impacts such as shallow landslides in lower latitude regions that are primarily precipitation driven, since it is difficult to determine the causes of precipitation change in those regions while poor land-use practices also may have contributed to landslide activity (e.g., Sidle and Ochiai, 2006).

3.5.6.3. Projected Changes

Given the projected rise of air temperature during the 21st century, it is *very likely* that mountain glacier areas will further reduce. European Alp glaciers are projected to decrease on the order of 20% to >50% (of the 2000 glacier area reference state) by about 2050 (Zemp et al., 2006; Huss et al., 2008) for a 2–3°C temperature increase over the 1961-1990 mean state. The warming climate favors rapid and sometimes unexpected developments of glacier decay and related mass movements (Huggel et al., 2010a), and as a result glaciers are increasingly in an imbalance. Projected glacier retreat in the 21st century will *likely* form new and potentially unstable lakes. Probable sites of new lakes have already been identified for some alpine glaciers (Frey et al., 2010). Of special concern in combination with existing and new natural and artificial lakes are rock slope and moraine instabilities that can result in impact waves and outburst floods. For rock slopes, the ongoing temperature rise will result in gradual permafrost degradation to increasing depths (Haeberli and Burn, 2002; Harris et al., 2009). At near-surface bedrock, the temperature rise is faster than at depth and warm permafrost areas (~-2 to 0°C), considered to be more susceptible to slope failures, may rise a few hundred meters during the next 100 years, depending on air temperature increase and the climate scenario applied (Noetzli and Gruber, 2009). The climate signal then penetrates to greater depth where the response of bedrock temperatures to ambient warming is delayed by decades or centuries (Noetzli et al., 2007). The response of firn and ice temperature to an increase in air temperature is typically faster and non-linear (Haeberli and Funk, 1991; Suter et al., 2001; Vincent et al., 2007). Latent heat effects from refreezing melt water can amplify the increase in air temperature in firn and ice (Huggel, 2009). At higher temperatures, there is more melting water and the strength of ice is lower, as a result, ice avalanches increase (Huggel et al., 2004; Caplan-Auerbach and Huggel, 2007).

Future extreme climatic events such as heat waves can result in rapid near-surface thawing and reach greater depth along advection corridors. Recent studies indicate that warm extremes can have a triggering effect for large landslides (rock and ice avalanches) but the physical processes are not yet well understood (Huggel et al., 2010b). For warm extremes with a potential to trigger slope instabilities (5-, 10- and 30-day warm events), based on the assessment of several RCMs it is projected that such high-temperature events for the period 2001-2050 compared to a 1951-2000 reference period increase about 1.5 to 4 times by 2050, and in some models up to 10 times (Huggel et al., 2010b).

Generally speaking, it is *likely* that continued permafrost degradation will lead to a general decrease of rock slope stability (Gruber and Haeberli, 2007). Future locations and timing of large rock avalanches are extremely difficult to predict, as they depend on a multitude of factors, including local geological conditions and failure mechanisms are not known in detail. There is some concern that the probability of large, combined events, such as landslides impacting lakes and generating large outburst floods, will increase (Haeberli and Hohmann, 2008; Huggel et al., 2010a).

It is *more likely than not* that the magnitude of shallow landslides and debris flows from recently deglaciated terrain will increase because of higher availability of unconsolidated sediment (Haeberli and Beniston, 1998), though future changes in rainfall amount and intensities will affect this projection. Changes in frequency of debris flows are difficult to project as they depend on the future frequency of debris flow triggering rainstorms. It is *more likely than not* that high-mountain debris flows will have earlier onset because of earlier snow melt. As extreme precipitation is *very likely* to increase in the future in many places of the world (Beniston et al., 2007; Christensen et al., 2007; Meehl et al., 2007b), shallow landslides in lower mountain ranges are *more likely than not* to increase.

Future changes in the magnitude and frequency of shallow landslides in temperate and tropical regions chiefly depend on frequency and intensities of rainfall events and anthropogenic land-use. Landslides can be triggered both by long-lasting (days to weeks) rainfall periods and short-term high-intensity rainfall events. In some regions social-economic pressure is likely to lead to land use practices that increase the frequency of landslides.

It is *very likely* that glacier retreat will continue and accelerate given that air temperature will continue to increase (Lemke et al., 2007). It is *likely* that new lakes will form in some regions in the 21st century due to glacier retreat, however, uncertainty on the projection of the location and timing of future glacier lake outburst floods is high (Frey et al., 2010). Projected changes in shallow landslide and debris flows in temperate regions are uncertain because of high uncertainty in projected changes of precipitation and in the land-use practices (Sidle and Ochiai, 2006).

3.5.7. Permafrost and High-Latitude Impacts

Permafrost is widespread in Arctic, Subarctic, and high-mountains regions, and in ice-free areas of Antarctica. Permafrost regions occupy approximately 23 million km^2 of land areas in the Northern Hemisphere (Zhang et al., 1999). The permafrost temperature regime is a sensitive indicator of climatic variability and change (Lachenbruch and Marshall, 1986; Osterkamp, 2005). Melting of massive ground ice and thawing of ice-rich permafrost can lead to subsidence of ground surface and to the formation of uneven topography known as thermokarst, generating dramatic changes in ecosystems, landscapes, and infrastructure performance (Nelson et al., 2001; Walsh, 2005). The active layer (the layer over the permafrost that thaws and freezes seasonally) plays an important role in cold regions because most ecological, hydrological, biogeochemical and pedogenic (soil-forming) activity takes place within it (Hinzman et al., 2005). Creation and drainage of thaw lakes and changes in lake surface area as a whole due to permafrost degradation would present challenges for ecosystems, natural resources, and the people who depend upon them (Hinzman et al., 2005; Smith et al., 2005a). Rapid Arctic coastal erosion increases threats to villages and industries.

3.5.7.1. Observed Changes

Observed evidence shows that temperatures at the top of the permafrost have increased by up to 3°C since the early 1980s (Lemke et al., 2007; Harris et al., 2009). Over the high Arctic such as in northern Alaska (Osterkamp, 2005, 2007) and Russia (Obserman and Mazhitova, 2001), permafrost temperatures have increased by about 2 to 3°C. The magnitude of permafrost temperature increase is up to 1.0ºC in the Interior of Alaska (Osterkamp, 2005, 2007), much of the Canadian Arctic (Smith et al., 2005b), Mongolia (Sharkhuu, 2003), and on the Tibetan Plateau (Cheng and Wu, 2007). Generally speaking, the magnitude of permafrost temperature increase in continuous permafrost regions is greater than in discontinuous permafrost regions. Increases in snow insulation effect may contribute significantly to the greater permafrost temperature increase in the high Arctic, and contribute to local and regional variability of permafrost temperature increase (Zhang et al., 2005). When the other conditions remain constant, active layer thickness is expected to increase in response to climate warming, especially in summer. Observed evidence shows that active layer thickness has increased about 20cm in the Russian Arctic from the early 1960s to 2000 (Zhang et al., 2005; Wu and Zhang, 2008), no significant trend in North American Arctic since the early 1990s (Brown et al., 2000), and up to 1.0 m from since the early 1980s over the Qinghai-Tibetan Plateau (Wu and Zhang, 2010). Extensive thermokarst development has been found in Alaska (Yoshikawa and Hinzman, 2003; Osterkamp et al., 2009), in the central Yakutia (Gavriliev and Efremov, 2003), and on the Qinghai-Tibetan Plateau (Niu et al., 2005). Significant expansion and deepening of thermokarst lakes were observed near Yakutsk with subsidence rates of 17 to 24 cm yr^{-1} from 1992–2001 (Fedorov and Konstantinov, 2003). Satellite remote sensing data show that thaw lake surface area has increased in continuous permafrost regions and decreased in discontinuous permafrost regions (Smith et al., 2005a).

The most sensitive regions of permafrost degradation are coasts with ice-bearing permafrost that are exposed to the Arctic Ocean. Due to the increased storm activity, long sea ice free seasons, and thawing permafrost, the Arctic coasts are retreating in a rapid rate of 2 to 3 m yr^{-1}(Rachold et al., 2003; Jorgenson and Brown, 2005) with an extreme of about 34 m yr^{-1} at Newtok, Alaska in 2003 (Karl et al., 2009). The rate of erosion along Alaska's northeastern coastline has doubled over the past 50 years (Karl et al., 2009).

3.5.7.2. Causes Behind the Changes

Increases in air temperature are in part responsible for the observed increase in permafrost temperature over the Arctic and Subarctic, and changes in snow cover also play a critical role (Osterkamp, 2005; Zhang et al., 2005). Earlier snowfall in autumn and thicker snow cover during winter provides a strong insulation effect, resulting in an increase of permafrost temperature much higher than that of air temperature in the Arctic. Changes in active layer thickness are primarily controlled by changes in length of thaw season and summer air temperature. The combination of Arctic sea ice retreat, storm activity increase, and permafrost degradation is responsible for rapid Arctic coast erosion in recent decades (Atkinson et al., 2006). Expansion of lake areas in the continuous permafrost zone may be due to thawing of ice-rich permafrost and melting of massive ground ice, while decreases in lake area in the discontinuous permafrost zone may be due to lake bottom drainage (Smith et al., 2005a). Overall, increased air temperature over high latitudes is primarily responsible for development of thermokarst terrains and thaw lakes.

3.5.7.3. Projected Changes

Widespread increases in active layer thickness in the Arctic and Subarctic are expected in response to global warming over the 21st century (IPCC, 2007a). Due to sea ice retreat, and permafrost degradation, with possibly a contribution from more storminess, the frequency and magnitude of the rate of Arctic coastal erosion will *likely* increase. For example, it has been projected that the coastal erosion rate at Newtok, Alaska will range from 11 to 25 m yr^{-1} in the next 20 years (Karl et al., 2009).

3.5.8. Sand and Dust Storms

Sand and dust storms are widespread natural phenomena in many parts of the world. Heavy dust storms disrupt human activities. Dust aerosols in the atmosphere can cause a suite of health impacts including respiratory problems (Small et al., 2001). The long-range transport of dust can affect conditions at long distances from the dust sources, linking the biogeochemical cycles of land, atmosphere and ocean (Martin and Gordon, 1988; Bergametti, 1998; Kellogg and Griffin, 2006). For example, dust from the Saharan region and from Asia may reach North America (McKendry et al., 2007).

3.5.8.1. Observed Changes

The Sahara (especially Bodélé Depression in Chad) and east Asia have been recognized as the strongest dust sources globally (Goudie, 2009). Over the past few decades, the frequency of dust events has increased in some regions such as the Sahel zone of Africa (Goudie and Middleton, 1992), and decreased in some other regions such as China (Zhang et al., 2003), but there seems to also be an increase in more recent years (Shao and Dong, 2006). Despite the importance of African dust, studies on long-term change in Sahel dust are limited. However, dust transported far away from the source region may provide some evidence of long-term changes in Sahel region. The African dust transported to Barbados began to increase in the late 1960s and through the 1970s; transported dust reached a peak in the early 1980s but remains high in to the present (Prospero and Lamb, 2003; Prospero et al., 2009). The dust frequency in Asia has decreased since the late 1970s

3.5.8.2. Causes Behind the Changes

Surface soil dust concentration during a sand and dust storm is controlled by a number of factors in a specific region. The driving force for the production of dust storms is the surface wind associated with cold frontal systems sweeping across the dry desert areas and lifting soil particles in the atmosphere. Dust emissions are also controlled by the surface conditions such as the desert coverage distributions, snow cover and soil moisture. In the Sahel region, the elevated high level of dust emission is related to the persistent drought since the 1970s, and to long-term changes in the North Atlantic Oscillation (Ginoux et al., 2004; Chiapello et al., 2005; Engelstaedter et al., 2006), and perhaps to North Atlantic SST as well (Wong et al., 2008). The long-term change in China dust storm frequency is influenced by climate variations, rather than desertification processes. The desert areas increased by ~2 to ~7% (Zhong, 1999) in China during 1960-2000, when the dust storm frequency decreased. A 44-year simulation study of Asian soil dust production with a dynamic desert distribution from 1960 to 2003 suggests that climatic variations play a major role in the declining trends in dust emission and storm frequencies (Zhang et al., 2003; Zhou and Zhang, 2003; Zhao et al., 2004) in China. Changes in wind (Wang et al., 2006c), meridional temperature gradients and cyclone frequencies (Qian et al., 2002), large-scale circulations such as the Asian polar vortex (Gong et al., 2006), the Siberia high (Ding et al., 2009), rainfall and vegetation (Zhou and Zhang, 2003) all contributed to the decrease in the observed dust frequency in China. Overall, the observed changes in dust activity are mainly the result of long-term changes in the climate, such as wind and moisture conditions in the dust source regions. Changes in large-scale circulation play an additional role in the long-distance transport of dust. However, understanding of the physical mechanisms of the long-term trends in dust activity is not complete, for example, there are a large number of potential causes affecting dust frequency in China, but their relative importance is uncertain.

3.5.8.3. Projected Changes

Future dust activity depends on two main factors: land use in the dust source regions, and climate both in the dust source region and large-scale circulation that affects long distance dust transport. Studies on projected future dust activity are very limited. It is difficult to project future land use. Precipitation, soil moisture, and runoff, have been projected to decrease in major dust source regions (Figure 10.12, Meehl et al., 2007b).Thomas et al., (2005) suggest that dune fields in southern Africa can be reactivated, and sand will become significantly exposed and move, as a consequence of 21st century climate warming. A study based on simulations from two climate models also suggests increased desertification in arid and semi-arid China, especially in the second half of the 21st century (Wang et al., 2009d). However, projected changes in wind are lacking.

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Chapter 3: Changes in Climate Extremes and their Impacts on the Natural Physical Environment

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Tables and Figures

Table 3.1: Overview of considered extremes and summary of observed and projected changes on global scale. Regional details on observed and projected changes in temperature and precipitation extremes are provided in Tables 3.2 and 3.3.

		Observed Changes (since 1950)	Attribution of Observed Changes	Projected Changes (until 2100)
Weather and climate elements	Temperature	*Very likely* decrease in number of unusually cold days and nights. *Very likely* increase in number of unusually warm days and nights, both on global and regional basis. *Likely* increase in warm spells, including heat waves.	*Likely* anthropogenic influence on trends in extreme temperature.	*Virtually certain* decrease in number of unusually cold days and nights (as defined with regard to 1960-1990 climate). *Virtually certain* increase in number of unusually warm days and nights (with regard to 1970-1990 climate). *Very likely increase in* warm spells, including heat waves (with regard to 1960-1990 climate).
	Precipitation	*Likely* global trend towards increases in the frequency of heavy precipitation events.	*More likely than not* anthropogenic influence on global trend towards increases in frequency of heavy precipitation events since 1950.	*Very likely* increase in frequency of heavy precipitation events over most areas of the globe.
	Winds	*Insufficient evidence*	*Insufficient evidence*	Increases *likely* in mid- to high-latitudes.
Phenomena related to weather and climate extremes	Monsoons	*More likely than not* changes in monsoon characteristics (precipitation amounts, patterns) but *insufficient evidence* for more specific statements.	*Insufficient evidence*	*Insufficient reliability of climate models*
	El Niño and other modes of variability	*More likely than not* change in center of El Niño Southern Oscillation (ENSO) episodes (more frequent central equatorial Pacific events). *Insufficient evidence* for more specific statements on ENSO trends. *Likely* trends in North Atlantic Oscillation (NAO) and Southern Annular Mode (SAM).	*Likely* anthropogenic influence on identified trends in NAO and SAM.	*Insufficient congruence of climate scenarios* for detailed statements on ENSO and other modes of variability.
	Tropical cyclones	*No trend* in global annual frequency of tropical cyclones over period of satellite observations (1970-present). *Lack of consensus* regarding fidelity and significance of non-zero frequency trends in individual ocean basins. *Significant increasing global trend* in intensity since 1983.	*Insufficient evidence*	*Likely* decrease or unchanged global frequency of tropical cyclones. *Likely* increase in mean maximum wind speed, but possibly not in all basins. *Likely* increase in tropical cyclone-related rainfall rates.
	Extra-tropical cyclones	*Likely* poleward shift in extratropical cyclones. *More likely than not* intensification of extratropical cyclones in high latitudes.	*Likely* anthropogenic influence on poleward shift.	*Likely* impacts on regional cyclone activity. *Likely* reduction of mid-latitude storms. *More likely than not* increase in high-latitude cyclone number and intensity.

Impacts on physical environment	Droughts	*Likely* increase in area affected by meteorological drought (precipitation deficit). *Likely* increase in total area affected by agricultural drought based on precipitation and temperature trends, as well as PDSI-based analyses, but *insufficient direct evidence* from actual observations (soil moisture deficits).	*More likely than not* influence on increase in area affected by droughts.	*Likely* increase in area affected by droughts.
	Floods	*Insufficient observations* of change in the magnitude and frequency in floods at the global level. *Likely* earlier spring peak in snow-dominated regions.	*More likely than not* anthropogenic influence on floods. *Likely* anthropogenic influence on earlier spring peak in snow-dominated regions.	*Insufficient literature* except for the earlier spring peak in snow-dominated regions. *Likely* earlier spring peak in snow-dominated regions.
	Extreme sea level and coastal impacts	*Likely* increase in extreme high water worldwide related to trends in mean sea level in the late 20th century.	*Likely* anthropogenic influence via mean sea level contributions.	*Very likely* that mean sea level rise will contribute to trends in extreme sea levels.
	Other impacts	*More likely than not* increase in large landslides in some regions. *Likely* thawing of permafrost with *likely* resultant physical impacts.	*Likely* anthropogenic influence on thawing of permafrost. *Insufficient evidence* for trends in other physical impacts in cold regions.	New and potentially unstable lakes are *likely* to form during the 21st century following glacier retreat. Earlier snow melt is *more likely than not* to result in earlier onset of high-mountain debris flows, and shallow landslides in lower mountain ranges are *more likely than not* to increase with the projected higher precipitation intensities. Arctic coastal erosion is *likely* to increase.

Table 3.2: Regional observed changes in temperature and precipitation extremes. Assessments for which no likelihood statements are available yet are displayed in grey in the Table (empty arrows on Figures 3.1 and 3.2).

Regions	**Sub-Region**	Tmax	Tmin	Warm Spells (Heat Waves)	Heavy Precipitation	Drought
		Observations	Observations	Observations	Observations	Observations
North America	All North America	*Likely* overall increase in unusually warm days, decrease in unusually cold days (Alexander et al., 2006).	*Likely* overall decrease in unusually cold nights, increase in unusually warm nights (Alexander et al., 2006).	Increase since 1960 (Kunkel et al., 2008).	*Likely* increase in many areas since 1950, (Trenberth et al., 2007; Kunkel et al., 2008).	No overall change, regional variability, 1930s drought dominates (Kunkel et al., 2008).
	W. North America	*Very likely* large increases in unusually warm days, large decreases in unusually cold days (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).	*Very likely* large decreases in unusually cold nights, large increases in unusually warm nights (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).	Increase in warm spells (Alexander et al., 2006).	General increase, decrease in some areas, (Alexander et al., 2006).	Slight increase since 1950, large variability, large drought of 1930s dominates (Kunkel et al., 2008).
	Central North America	*Very likely* small increases in unusually warm days, decreases in unusually cold days (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).	*Likely* small decreases in unusually cold nights, increases in unusually warm nights (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).	Some areas increase, others decrease (Alexander et al., 2006).	*Very likely* increase since 1950, (Alexander et al., 2006).	Slight decrease since 1950, large variability, large drought of 1930s dominates (Kunkel et al., 2008).
	E. North America	*Very likely* increases in unusually warm days, decreases in unusually cold days (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).	*Very likely* decreases in unusually cold nights, increases in unusually warm nights (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).	Some areas increase, others decrease (Alexander et al., 2006).	*Very likely* increase since 1950 (Alexander et al., 2006).	Slight decrease since 1950, large variability, large drought of 1930s dominates (Kunkel et al., 2008).
	Alaska	*Very likely* large increases in unusually warm days, large decreases in unusually cold days (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).	*Very likely* large decreases in unusually cold nights, large increases in unusually warm nights (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).		Suggestion of increase, no significant trend (Kunkel et al., 2008).	*More likely than not* slight increase since the 1950s (Kunkel et al., 2008).
	E. Canada,	*Likely* increases in unusually	*Likely* decreases in unusually	Some areas increase, most	Increase in a few areas	

	Greenland, Iceland	warm days in some areas, decrease in others. Decreases in unusually cold days in some areas, increase in others (Robeson, 2004; Alexander et al., 2006; Vincent and Mekis, 2006; Trenberth et al., 2007; Kunkel et al., 2008; Peterson et al., 2008a).	cold nights, increases in unusually warm nights (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008a).	others decrease (Alexander et al., 2006).	(Alexander et al., 2006).	
Europe	All Europe	*Very likely* increases in unusually warm days, decreases in unusually cold days (Kiktev et al., 2003; Bartholy and Pongracz, 2007; Della-Marta et al., 2007a; Trenberth et al., 2007; Kurbis et al., 2009).	*Very likely* decreases in unusually cold nights, increases in unusually warm nights (Kiktev et al., 2003; Bartholy and Pongracz, 2007; Trenberth et al., 2007; Kurbis et al., 2009).		*More likely than not* increase in most areas, decrease in a few areas, (Alexander et al., 2006; Bartholy and Pongracz, 2007).	
	N. Europe	*Very likely* increases in unusually warm days, decreases in unusually cold days (Kiktev et al., 2003; Bartholy and Pongracz, 2007; Della-Marta et al., 2007a; Trenberth et al., 2007; Kurbis et al., 2009).	*Very likely* decreases in unusually cold nights, increases in unusually warm nights (Kiktev et al., 2003; Bartholy and Pongracz, 2007; Trenberth et al., 2007; Kurbis et al., 2009).		*More likely than not* increase in most areas, decrease in a few areas, (Alexander et al., 2006; Bartholy and Pongracz, 2007).	
	S. Europe and Mediterranean	*Likely* large increases in unusually warm days, *likely* decreases in unusually cold days (Della-Marta et al., 2007a; Trenberth et al., 2007).	*Likely* decrease in unusually cold nights, increases in unusually warm nights (Trenberth et al., 2007).	*Likely* large increase in heatwave length in the Iberian Peninsula (Della-Marta et al., 2007a). *Likely* large increase in heat wave intensity, heat wave number and heat wave length in summer in the Eastern Mediterranean (Kuglitsch et al., 2010).	*More likely than not* increase in most areas, decrease in a few areas, (Alexander et al., 2006).	
Africa	All Africa					
	W. Africa	*Likely* increases in unusually	*Likely* decreases in unusually		Increase in many areas	

		warm days, decreases in unusually cold days (Trenberth et al., 2007).	cold nights, increases in unusually warm nights (Trenberth et al., 2007).		(Trenberth et al., 2007).	
	E. Africa	Increases in unusually warm days, decreases in unusually cold days (Trenberth et al., 2007).	Decreases in unusually cold nights, increases in unusually warm nights (Trenberth et al., 2007).		Decrease (Trenberth et al., 2007).	
	S. Africa	Increases in unusually warm days, decreases in unusually cold days (Trenberth et al., 2007).	Decreases in unusually cold nights, increases in unusually warm nights (Trenberth et al., 2007).		Increase (Trenberth et al., 2007).	
	Sahara	Increases in unusually warm days, decreases in unusually cold days (Trenberth et al., 2007).	Decreases in unusually cold nights, increases in unusually warm nights (Trenberth et al., 2007).			
Central and South America	All South America					
	Central America and northern South America	Increases in unusually warm days, decreases in unusually cold days (Aguilar et al., 2005; Alexander et al., 2006; Brown et al., 2008).	Decreases in unusually cold nights, increases in unusually warm nights (Aguilar et al., 2005; Alexander et al., 2006; Brown et al., 2008).	A few areas increase, a few others decrease (Aguilar et al., 2005; Alexander et al., 2006).	Increase in many areas, decrease in a few areas, (Aguilar et al., 2005; Alexander et al., 2006).	Increase of CDD in some areas, others decrease (Aguilar et al., 2005).
	Amazon	Increases in unusually warm days, decreases in unusually cold days (river mouth (Alexander et al., 2006).	Decreases in unusually cold nights, increases in unusually warm nights (Alexander et al., 2006; Dufek et al., 2008).		Increase in many areas, decrease in a few areas (Alexander et al., 2006; Haylock et al., 2006b).	Slight decrease of CDD (Dufek et al., 2008).
	Northeastern Brazil	Increases in unusually warm days (Silva and Azevedo, 2008).	Increases in unusually warm nights (Silva and Azevedo, 2008).		Increase in many areas, decrease in a few areas, (Alexander et al., 2006; Haylock et al., 2006b; Santos and Brito, 2007; Silva and Azevedo, 2008; Santos et al., 2009).	Increase of CDD in many areas, decrease in a few areas (Santos and Brito, 2007; Silva and Azevedo, 2008; Santos et al., 2009).
	Southeastern South America	Increases in unusually warm days in some areas, decrease in others. Decreases in unusually cold days in some areas, increase in others, (Rusticucci and Barrucand, 2004; Vincent	Decreases in unusually cold nights, increases in unusually warm nights (Rusticucci and Barrucand, 2004; Vincent et al., 2005; Alexander et al., 2006; Brown et al., 2008;	Some areas increase, others decrease (Alexander et al., 2006).	Increase (Alexander et al., 2006; Dufek et al., 2008; Sugahara et al., 2009; Penalba and Robeldo, 2010).	Slight increase, large variability, (Haylock et al., 2006b; Dufek and Ambrizzi, 2008; Dufek et al., 2008; Llano and Penalba, 2010; Penalba

		et al., 2005; Alexander et al., 2006; Brown et al., 2008; Rusticucci and Renom, 2008; Marengo et al., 2009b).	Rusticucci and Renom, 2008; Marengo et al., 2009b).			and Robeldo, 2010).
	W. Coast South America	Increases in unusually warm days in some areas, decrease in others. Decreases in unusually cold days in some areas, increase in others, (Rosenbluth et al., 1997; Vincent et al., 2005; Alexander et al., 2006).	Decreases in unusually cold nights, increases in unusually warm nights (Rosenbluth et al., 1997; Vincent et al., 2005; Alexander et al., 2006).		Decrease in many areas, increase in a few areas (Alexander et al., 2006; Haylock et al., 2006b).	Slight increase in some areas, (Dufek et al., 2008).
Asia	All Asia					
	N. Asia	*Likely* increases in unusually warm days, decreases in unusually cold days (Alexander et al., 2006).	Decreases in unusually cold nights, increases in unusually warm nights (Alexander et al., 2006; Trenberth et al., 2007).		Increase, (Trenberth et al., 2007).	
	Central Asia	*Likely* increases in unusually warm days, decreases in unusually cold days (Alexander et al., 2006; Trenberth et al., 2007).	Decreases in unusually cold nights, increases in unusually warm nights (Alexander et al., 2006; Trenberth et al., 2007).			
	East Asia	*Likely* increases in unusually warm days, decreases in unusually cold days (Trenberth et al., 2007; Ding et al., 2009).	Decreases in unusually cold nights, increases in unusually warm nights (Trenberth et al., 2007; Ding et al., 2009).	Increase in warm season heat waves in China (Ding et al., 2009), but decline in all warm spells (Alexander et al., 2006).		
	S.E. Asia	Increases in unusually warm days, decreases in unusually cold days, northern part (Alexander et al., 2006).	Decreases in unusually cold nights, increases in unusually warm nights, northern part. (Alexander et al., 2006).			
	S. Central Asia	Decrease in unusually warm and cold days, (Alexander et al., 2006).	Decreases in unusually cold nights, increases in unusually warm nights (Alexander et al., 2006).			
	Tibetan Plateau	Decrease in unusually warm and cold days (Alexander et al., 2006).	Decreases in unusually cold nights, increases in unusually warm nights (Alexander et al., 2006).			

	W. Asia	*More likely than not* decrease in unusually cold days and very likely increase in unusually warm days (Choi et al., 2009; Rahimzadeh et al., 2009; Rehman, 2010).	*Likely* decrease in unusually cold nights and likely increase in unusually warm nights (Choi et al., 2009; Rehman, 2010).		*More likely than not* decrease in heavy precipitation events. (Kwarteng et al., 2009; Rahimzadeh et al., 2009).	*Likely* increase in drought (Kwarteng et al., 2009; Rahimzadeh et al., 2009).
Australia/ New Zealand	N. Australia/NZ	Increases in unusually warm days, decreases in unusually cold days (Alexander et al., 2006; Trenberth et al., 2007).	Decreases in unusually cold nights, increases in unusually warm nights (Alexander et al., 2006).			
	S. Australia/NZ	Increases in unusually warm days, decreases in unusually cold days (Alexander et al., 2006; Trenberth et al., 2007).	Decreases in unusually cold nights, increases in unusually warm nights (Alexander et al., 2006).			

Table 3.3: Projected regional changes in temperature and precipitation extremes. The key for the employed abbreviations is found below the Table. Assessments for which no likelihood statements are available yet are displayed in grey in the Table (empty arrows on Figures 3.3 and 3.4).

Regions	**Sub-Region**	Tmax [HD: hot days CD: cold days]		Tmin [WN: warm nights CN: cold nights]		Warm Spells [HWD: heat wave duration]		Heavy precipitation [HPD: heavy precipitation days HPC: heavy precipitation contribution]		Dry spells [CDD: consecutive dry days] [EDI: effective dry days]	
		Projections		Projections		Projections		Projections		Projections	
North America	All North America										
	Canada	HD *very likely* to increase & CD *very likely* to decrease over all regions (Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007b).	A	WN *very likely* to increase & CN *very likely* to decrease over all regions (Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007b).	**A**	*Very likely* more frequent heat waves & warm spells over all regions (Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007b).	A	*Very likely* more frequent & intense HPD over most regions (Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007b).	A		
	USA & N Mexico	HD *very likely* to increase & CD *very likely* to decrease over all regions (Christensen et al., 2007; Karl et al., 2008).	A	WN *very likely* to increase & CN *very likely* to decrease over all regions (Christensen et al., 2007; Karl et al., 2008).	A	*Very likely* more frequent heat waves & warm spells over all regions (Christensen et al., 2007; Karl et al., 2008).	A	*Very likely* more frequent & intense HPD over most regions except SW US and N Mexico (Christensen et al., 2007; Karl et al., 2008).	A	*Likely* increase in drought area in SW US & N Mexico. No change or possible decline in other regions (Christensen et al., 2007; Karl et al., 2008).	A
	W. North America										
	Central North America										
	E. North America										
	Alaska										
	E. Canada, Greenland, Iceland										
	All Europe	HD *very likely* to	A	CN *very likely* to	A	HWD *very likely* to	A	*Very likely* increases in	A	Little/no change in	A

		increase – largest increases in summer and C/S Europe & smallest in N Europe (Scandinavia) (Goubanova and Li, 2007; Kjellstrom et al., 2007; Koffi and Koffi, 2008). Tmax changes generally > mean changes (Diffenbaugh et al., 2007; Kjellstrom et al., 2007; Fischer and Schär, 2009; Fischer and Schär, 2010).	**R**	decrease – largest decreases in winter & E Europe & Scandinavia (Goubanova and Li, 2007; Kjellstrom et al., 2007; Sillmann and Roeckner, 2008). Tmin changes generally > mean changes (Diffenbaugh et al., 2007; Goubanova and Li, 2007; Kjellstrom et al., 2007). WN *very likely* to increase – largest increases in Mediterranean (Sillmann and Roeckner, 2008).	G **R**	increase (also increases in intensity & frequency) – likely by a factor of at least (Beniston et al., 2007; Christensen et al., 2007; Kysely and Beranova, 2009)	**R**	HPD and decreases in return periods of long (e.g., 5-day) and short (1-day) HP across most of Europe, but uncertainty in magnitude of changes (Beniston et al., 2007; Fowler et al., 2007b; Sillmann and Roeckner, 2008; Kendon et al., 2009). *Likely* increase in HPC in some regions (Boberg et al., 2009a; Kendon et al., 2009). *Likely* greater changes in extremes and rarer events than mean. *Very likely* increase in HP intensity (& increase in HPC) despite decrease in summer mean in some regions – e.g. C Europe (Beniston et al., 2007; Fowler et al., 2007b; Haugen and Iverson, 2008; May, 2008; Kysely and Beranova, 2009).	**G** **R**	CDD in N Europe, increase in C Europe and largest increases in S Europe. 21 Frequency/length of CDD increases over much of the continent – length increases in the S (May, 2008).	G R
Europe	N. Europe	See all Europe		See all Europe		HWD *very likely* to increase, but summer increases < than in S Europe (Beniston et al., 2007; Kysely and Beranova, 2009).	A **R**	*Very likely* increases in HP (intensity and frequency) north of 45N in winter (Frei et al., 2006; Beniston et al., 2007; Kendon et al., 2008).	A R	Little/no change in CDD (Sillmann and Roeckner, 2008).	A G
	S. Europe and Mediterranean	*Very likely* large increase in HD (Fischer and Schär, 2009; Giannakopoulos et al.,	A B G R	WN *very likely* to increase –*likely* largest changes in E Mediterranean (Sillmann	A B **G**	*Very likely* large increase in HWD (also increases in intensity and frequency) - *likely*	A B G **R**	About *as likely as not* increase in HP intensity in all seasons except summer over parts of the	A G **R**	CDD *very likely* to increase by a month or more, especially in S Iberian Peninsula,	A B **G** R

		2009; Fischer and Schär, 2010).		and Roeckner, 2008; Giannakopoulos et al., 2009).		largest increases in SW, S & E (Beniston et al., 2007; Diffenbaugh et al., 2007; Koffi and Koffi, 2008; Giannakopoulos et al., 2009; Fischer and Schär, 2010).		region, but decrease in some parts, e.g., Iberian Peninsula (Goubanova and Li, 2007; Giorgi and Lionello, 2008; Giannakopoulos et al., 2009).		E Adriatic and S Greece (Beniston et al., 2007; Sillmann and Roeckner, 2008; Giannakopoulos et al., 2009).	
Africa	All Africa										
	W. Africa										
	E. Africa										
	S. Africa										
	Sahara										
Central and South America	All South America										
	Central America and northern South America										
	Amazon	*Lack of evidence*		*Very likely* increase of warm nights (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R	*Very likely* to increase (Tebaldi et al., 2006).	A **G**	*Insufficient evidence* (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R	*Insufficient evidence* (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R
	Northeastern Brazil	*Lack of evidence*		*Likely* increase of warm nights (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R	*Likely* to increase (Tebaldi et al., 2006).	A **G**	*Insufficient evidence* (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R	*Likely* to increase (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R
	Southeastern South America	*Lack of evidence*		*Very likely* increase of warm nights (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R	*Likely* to increase (Tebaldi et al., 2006).	A **G**	*Very likely* to increase (Tebaldi et al., 2006; Marengo et al., 2009a; Nunez et al., 2009).	A **G** R	*Likely* to increase (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R
	Western Coast of South America	*Lack of evidence*		*Likely* increase of warm nights (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R	*Very likely* to increase (Tebaldi et al., 2006).	A **G**	*Likely* to increase in the tropics and likely to decrease in the extratropics (Tebaldi et al., 2006; Marengo et al., 2009a).	A **G** R	*Insufficient evidence* (Tebaldi et al., 2006; Marengo et al., 2009a)	A **G** R

	All Asia										
Asia	N. Asia									General drought (EDI<-1) less frequent & shorter duration. (Kim and Byun, 2009)	A **G**
	Central Asia										
	East Asia	Tmax (95th percentile) increases (by up to 4-5°C) in Korea. HD increases (by up to 26 days) in Korea (Boo et al., 2006; Im and Kwon, 2007; Im et al., 2008; Koo et al., 2009; Im et al., 2010).	A B R	Tmin (5th percentile) increases (by up to 7-9°C) in Korea (Boo et al., 2006; Koo et al., 2009; Im et al., 2010).	A B R			HP & HPD increases in Korea (Boo et al., 2006; Im et al., 2010). HPD increase in Yangtze and Japan (Kimoto et al., 2005; Kusunoki and Mizuta, 2008). HP frequency (hourly & daily) increases (Kitoh et al., 2009). 50-year HP events increase in mid-lower Yangtze (Su et al., 2009).	A B G R	Extreme drought (EDI<-2) intensifies in the southern area & Asian monsoon region (Kim and Byun, 2009).	A **G**
	S.E. Asia									Extreme drought (EDI<-2) intensifies in the Asian monsoon region (Kim and Byun, 2009).	A **G**
	S. Asia	Tmax increases by 2°C in most areas of India (Kumar et al., 2006).	A R	Tmin increases by 5°C in India (Kumar et al., 2006).	A R			Increases in maximum 1-day & 5-day precipitation in India – especially in western Ghats & NW peninsular India (Wakazuki et al., 2008).	A R	Extreme drought (EDI<-2) intensifies in the Asian monsoon region (Kim and Byun, 2009).	A **G**
	W. Asia									Extreme drought (EDI<-2) more frequent & intensifies (especially in Syria & vicinity). (Kim and	A **G**

										Byun, 2009)	
	Tibetan Plateau										
Australia/New Zealand	Australia			WN increase everywhere. Largest increases in N (~60%) compared with S (~30%). Most consistent changes in inland regions (Alexander and Arblaster, 2009).	A **G**	HWD increases everywhere. Strongest increases in NW & most consistent increases inland (Alexander and Arblaster, 2009).	A **G**	HPD tend to increase in E & decrease in W half of country – but considerable inter-model inconsistencies. HPC tends to increase everywhere – but considerable inter-model inconsistencies (Alexander and Arblaster, 2009).	A **G**		

Notes:

Codes for projection period & emissions scenarios:

A: Projections for end of century (2071-2100 minus 1961-1990 or 2080-2099 minus 1980-1999) and A2 or A1B emissions scenarios.

B: Prior to 2050, any SRES.

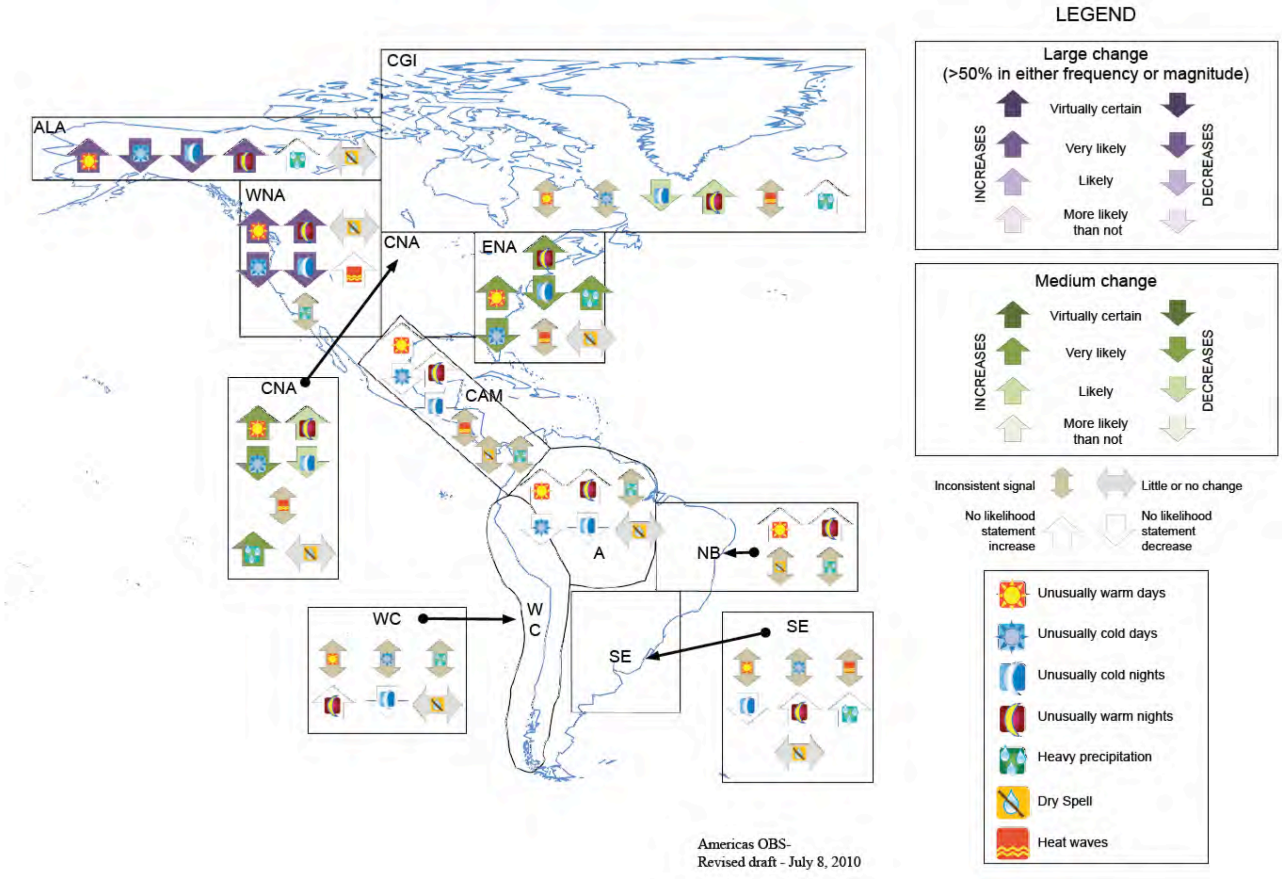
Codes for downscaling method:

G: Based on GCM simulations. Bold: multi-GCM.

R: Based on RCM simulations. Bold: multi-GCM. Underlined: multi-RCM.

EDI: Effective Drought Index. Calculated from precipitation only – considers Effective Precipitation: the summed value of daily precipitation with a time-dependent reduction function.

1



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3
4
5 **Figure 3.1:** Regional observed changes in temperature and precipitation extremes (Americas)
6

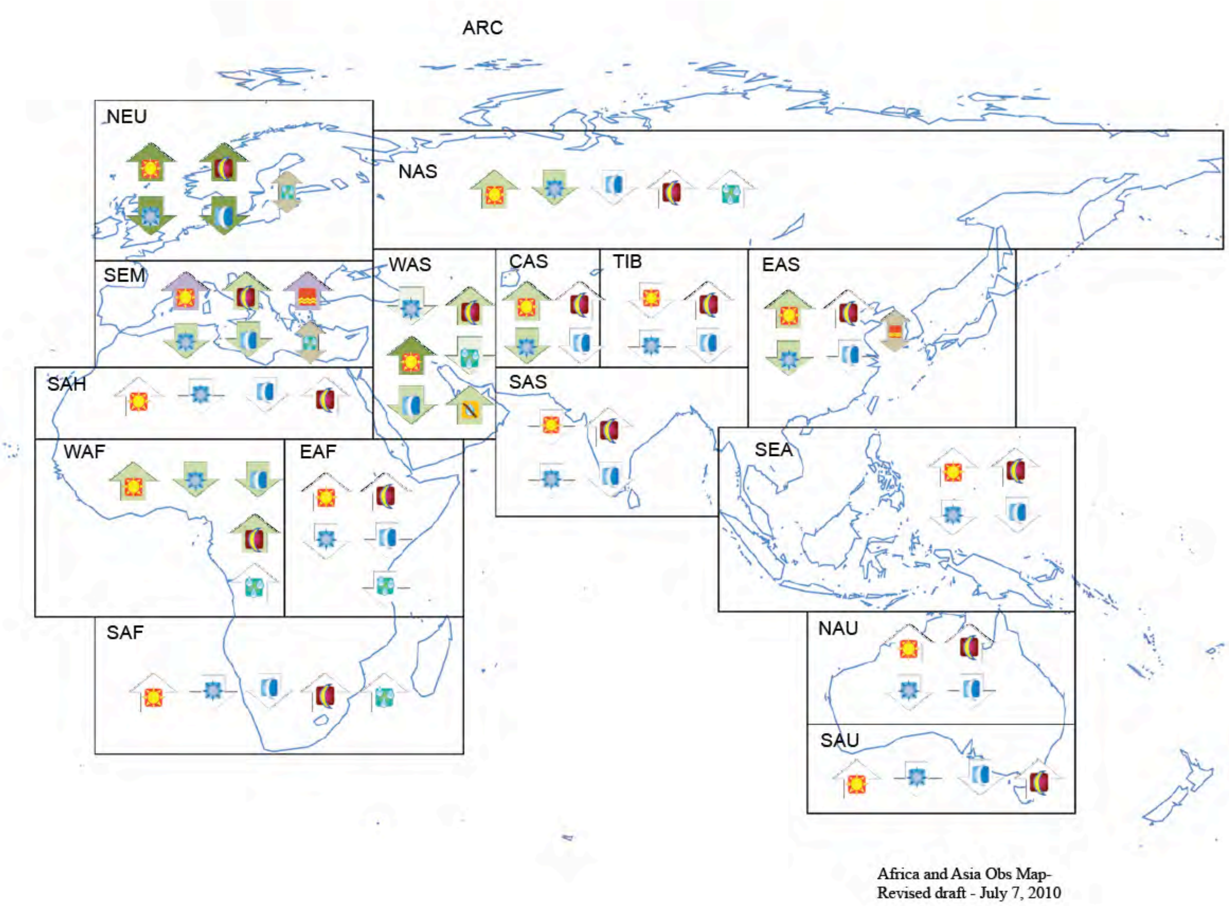


Figure 3.2: Regional observed changes in temperature and precipitation extremes (Europe, Africa, Asia and Oceania). See Figure 3.1 for definition of symbols

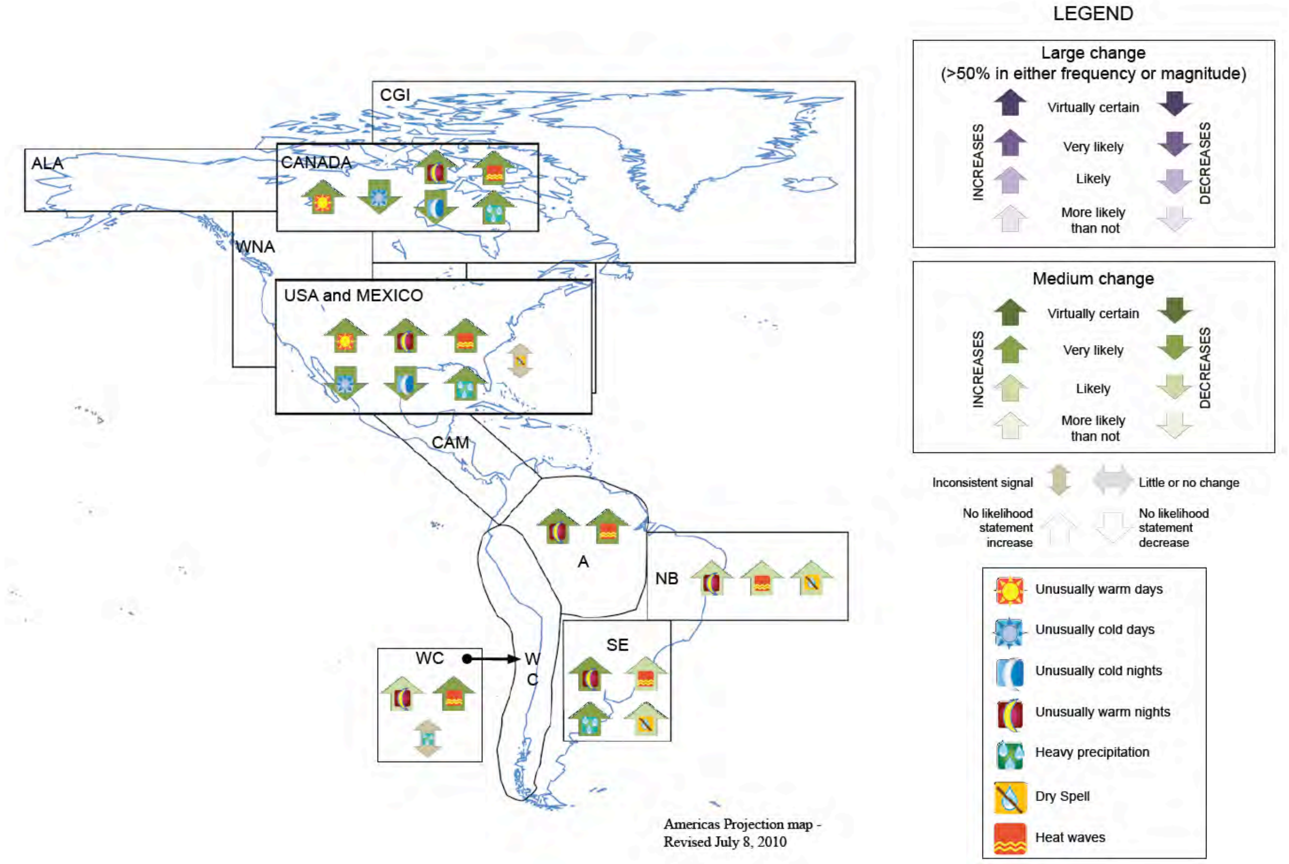
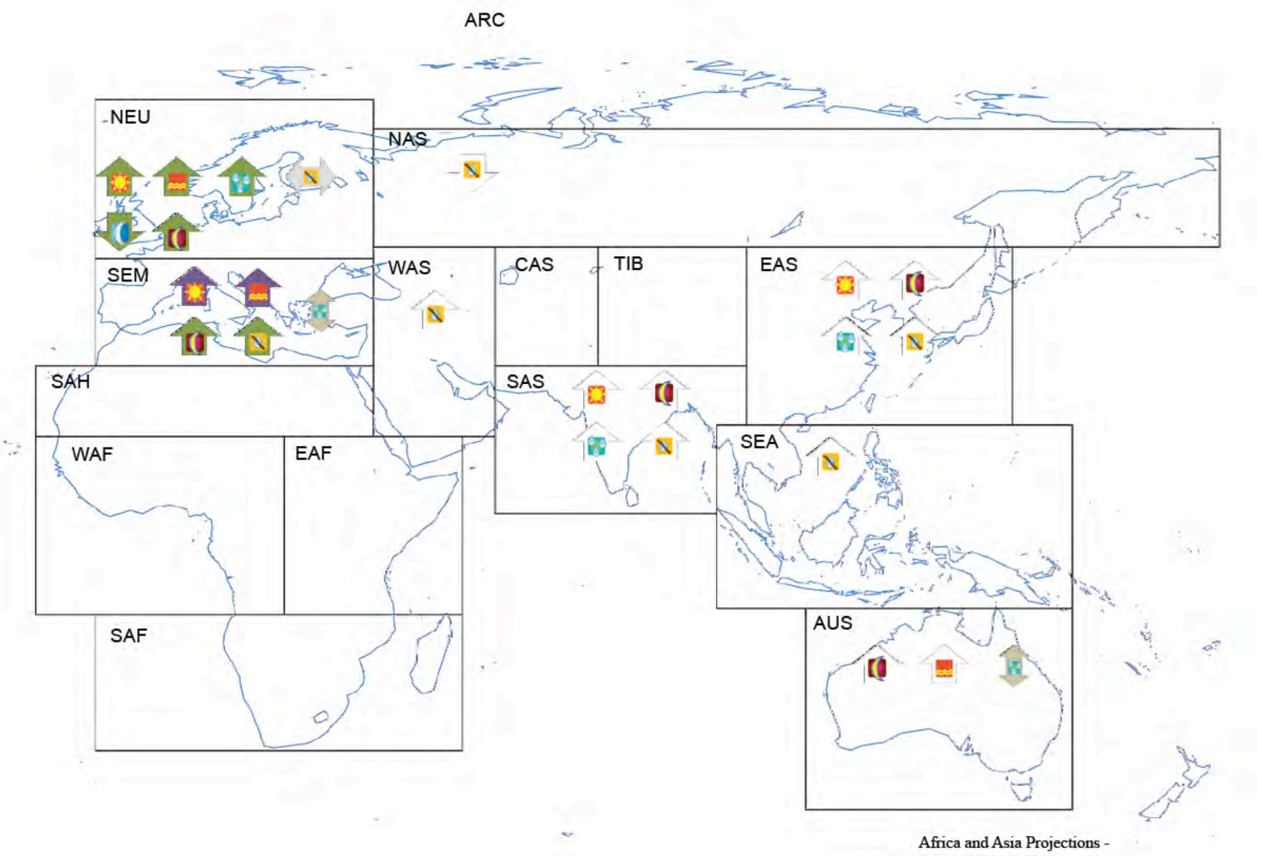
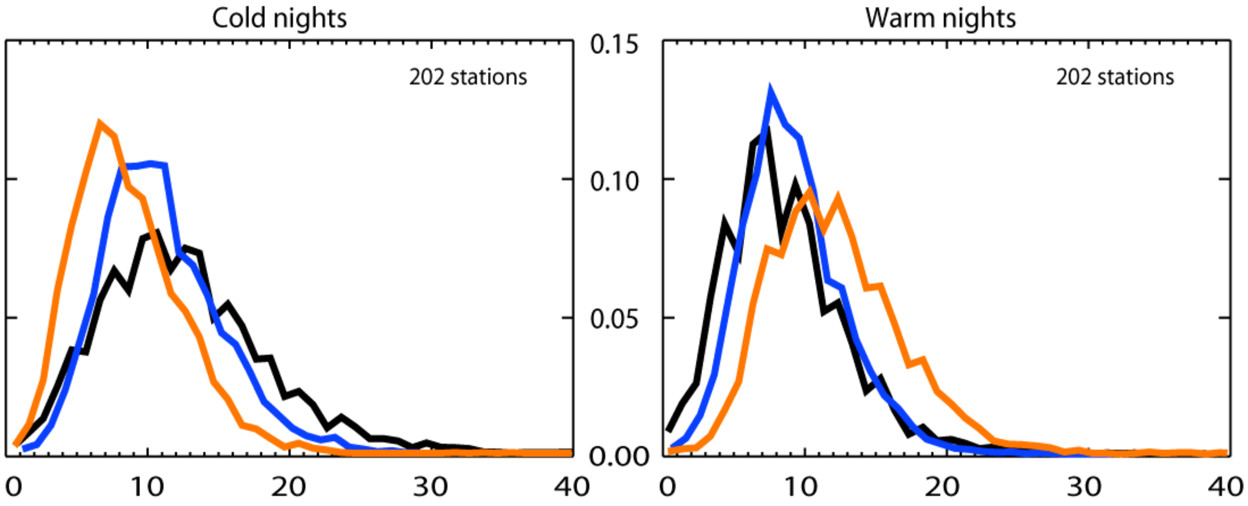


Figure 3.3: Regional projected changes in temperature and precipitation extremes (Americas)



Africa and Asia Projections -
Revised July 7, 2010

Figure 3.4: Regional projected changes in temperature and precipitation extremes (Europe, Africa, Asia, and Oceania). See Figure 3.3. for definition of symbols.



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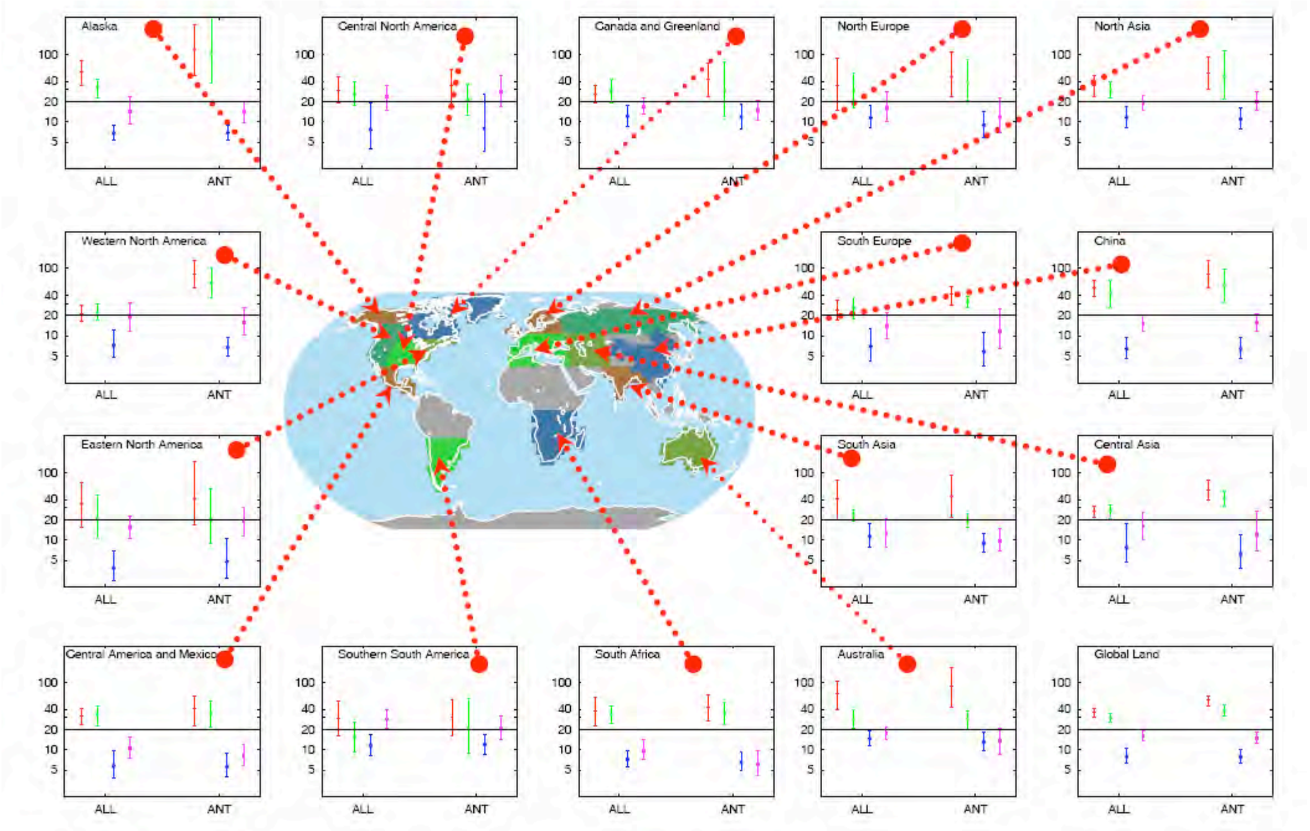

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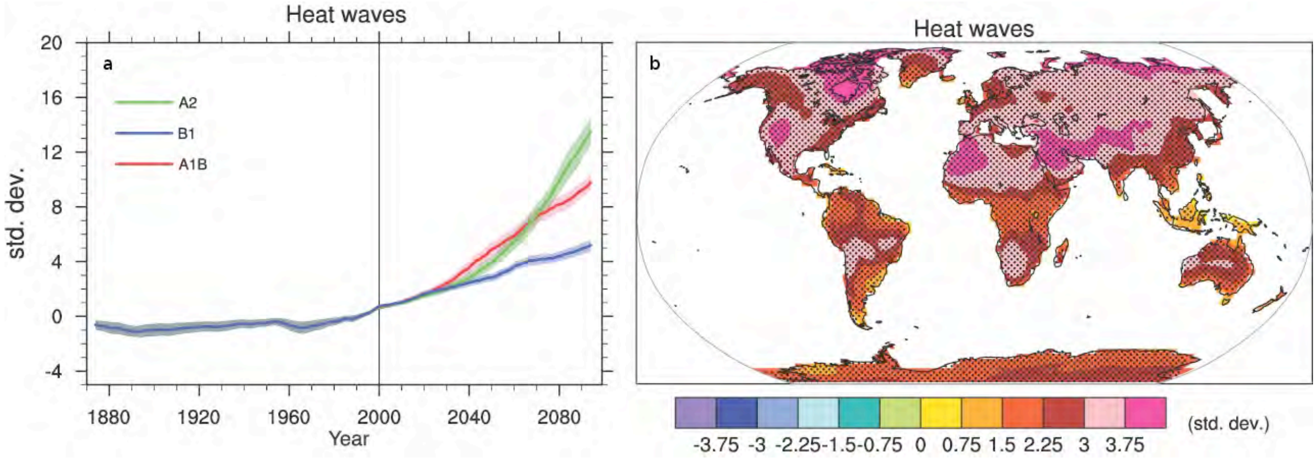

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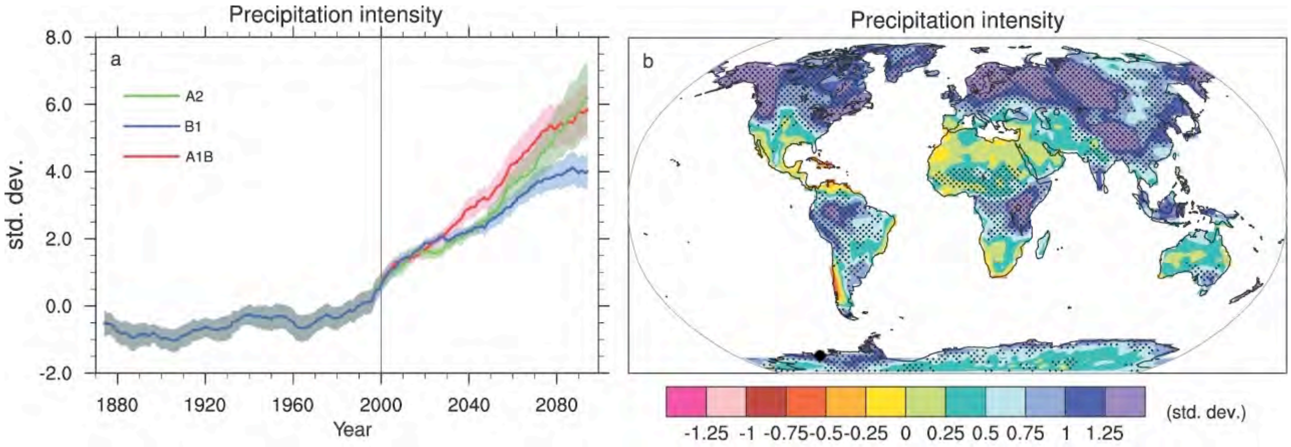

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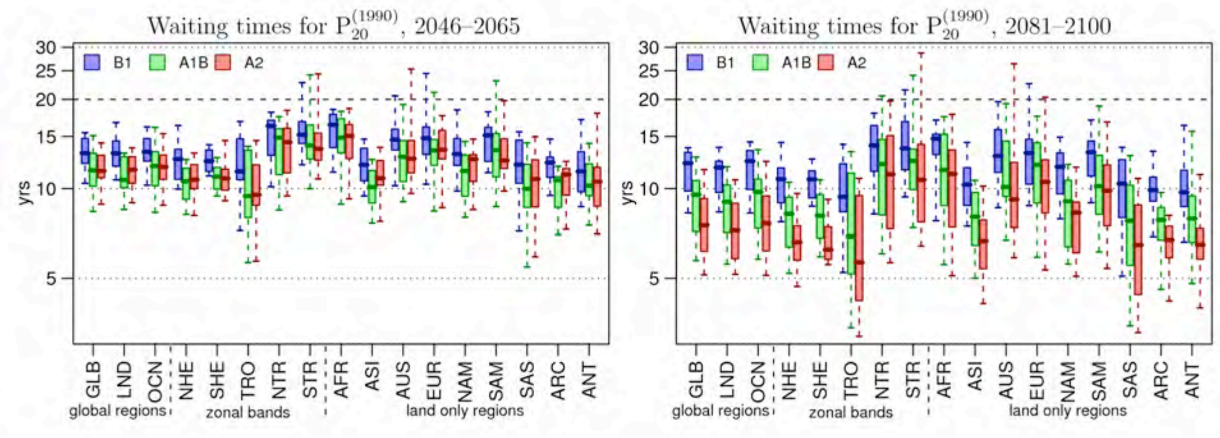

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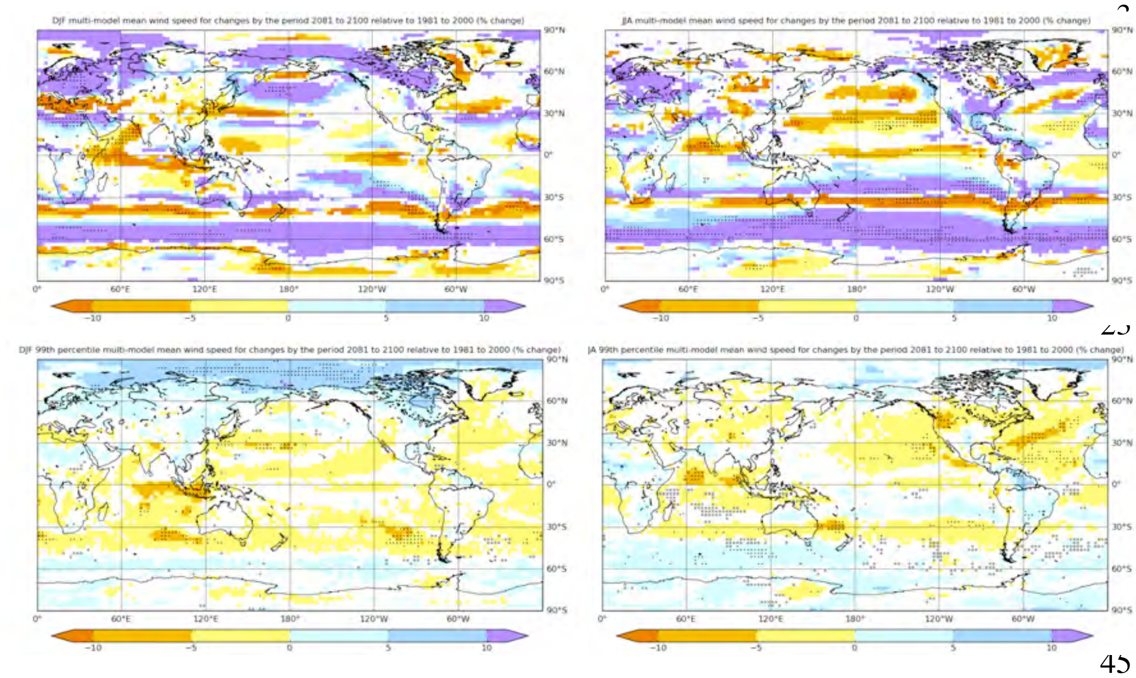
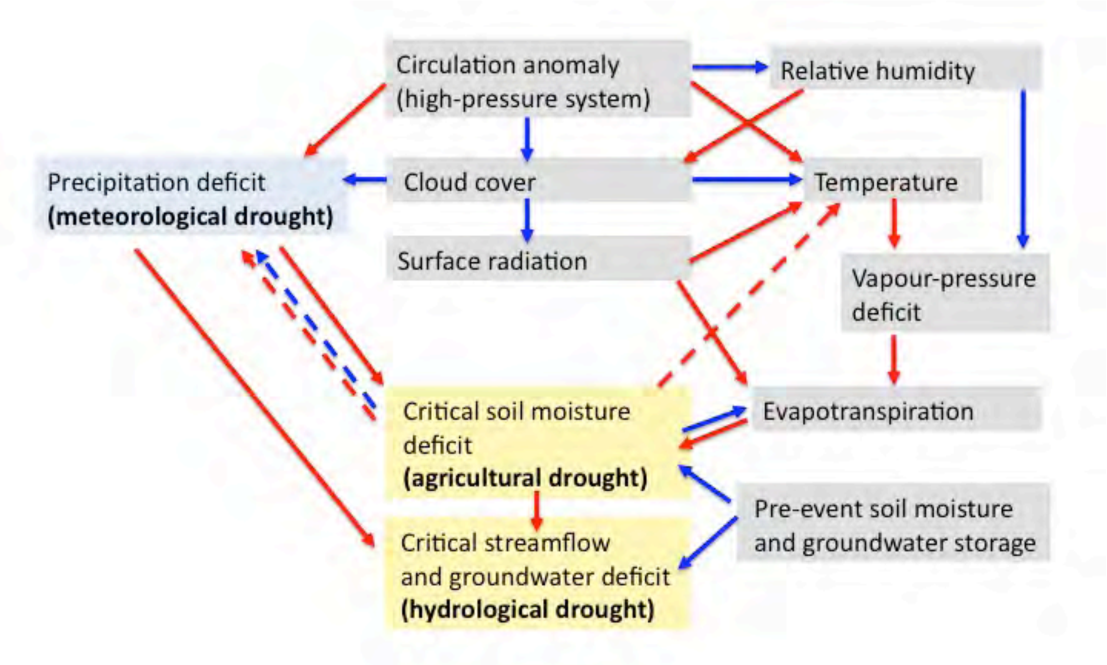


Figure 3.10: The average of the multi-model 10 m mean wind speeds (top) and 99th percentile daily wind speeds (bottom) for the period 2080 to 2099 relative to 1980 to 1999 (% change) for December to February (left) and June to August (right) plotted only where more than 66% of the models agree on the sign of the change. Fine black stippling indicates where more than 90% of the models agree on the sign of the change and bold grey stippling (in white or light coloured areas) indicates where 66% of models agree on a small change between ±2 %. From McInnes et al., (2010).



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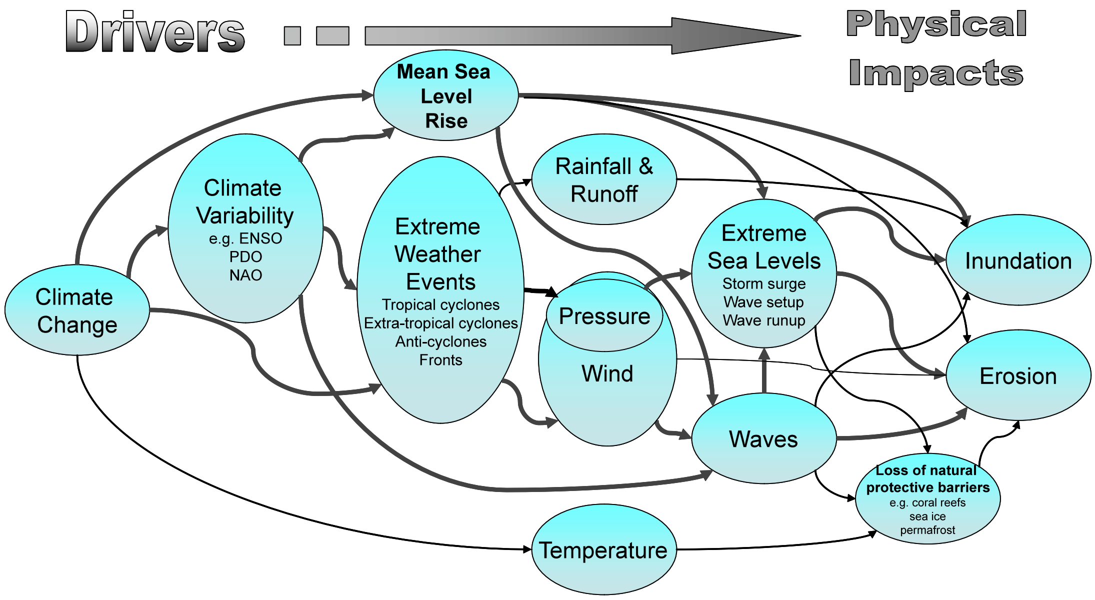
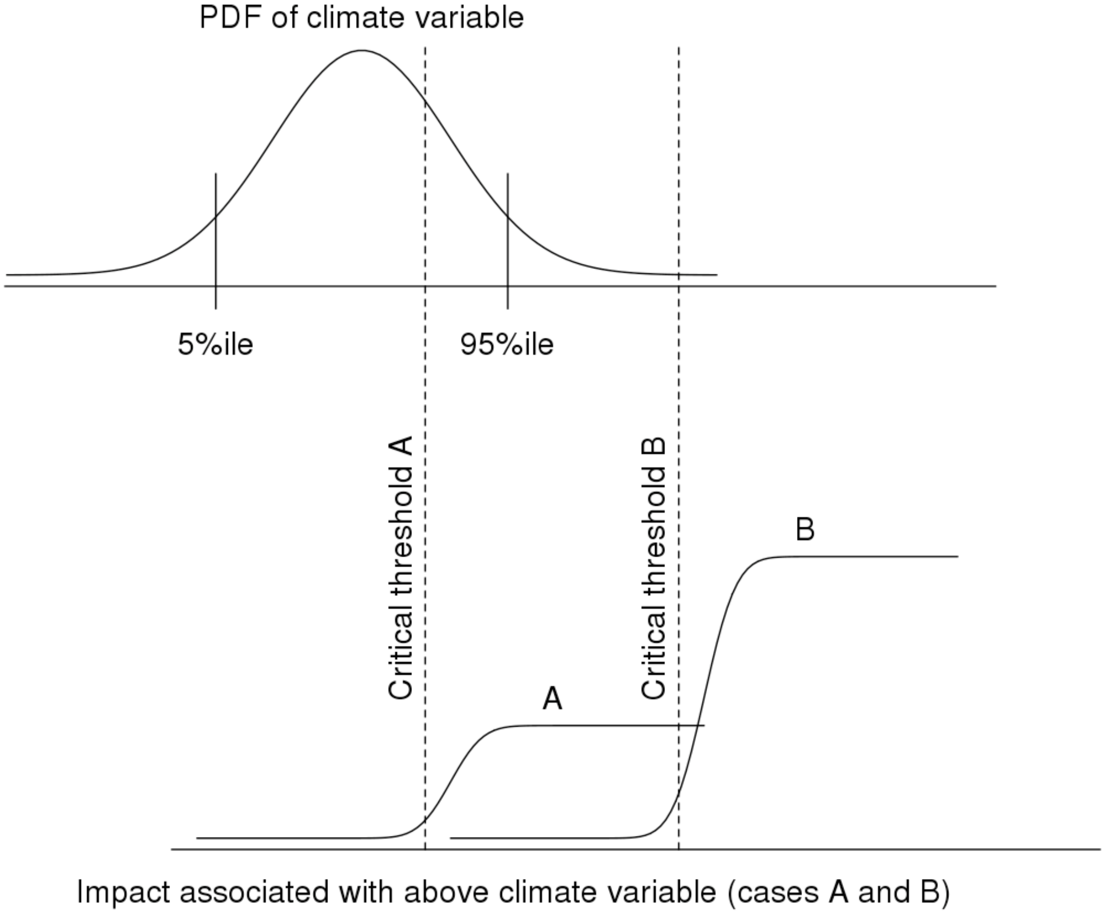
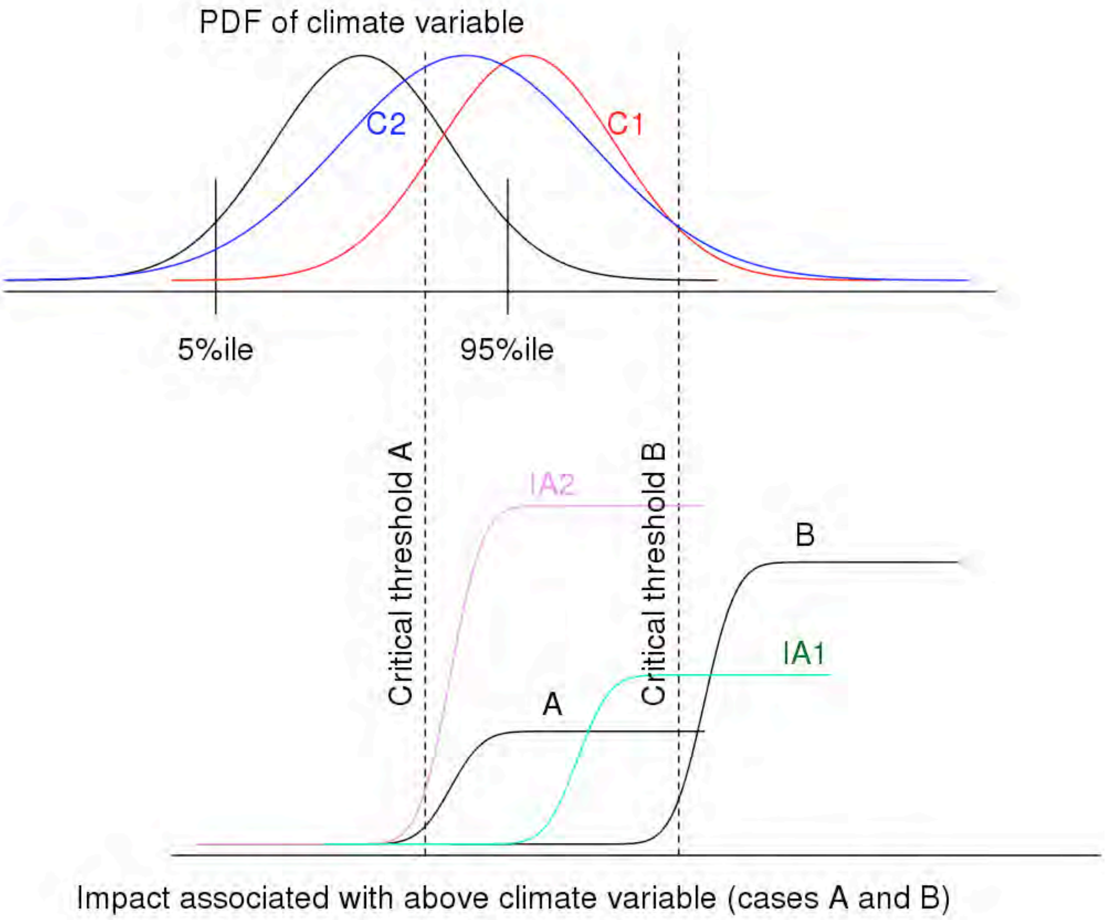


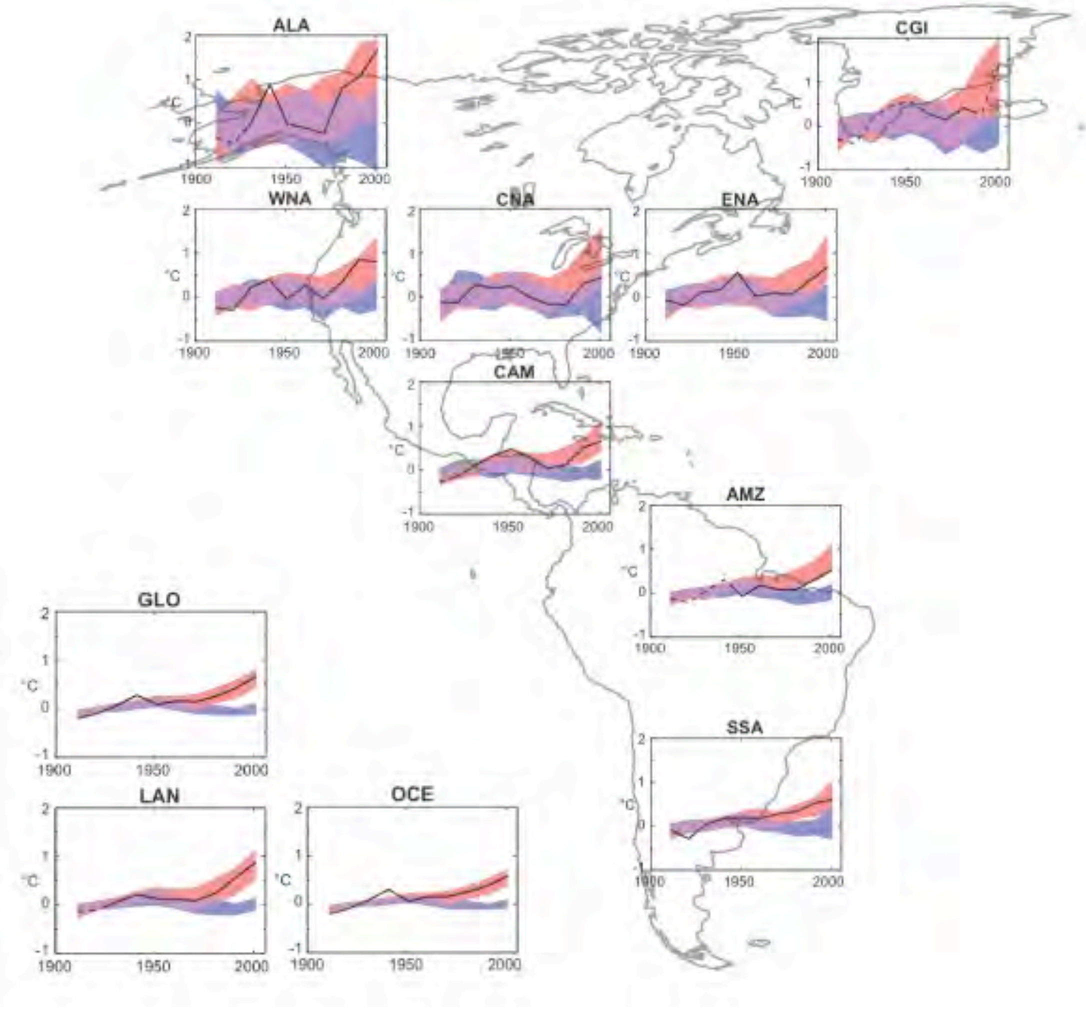
Figure 3.12: Relationships between climate, weather phenomena and physical impacts in the coastal zone.



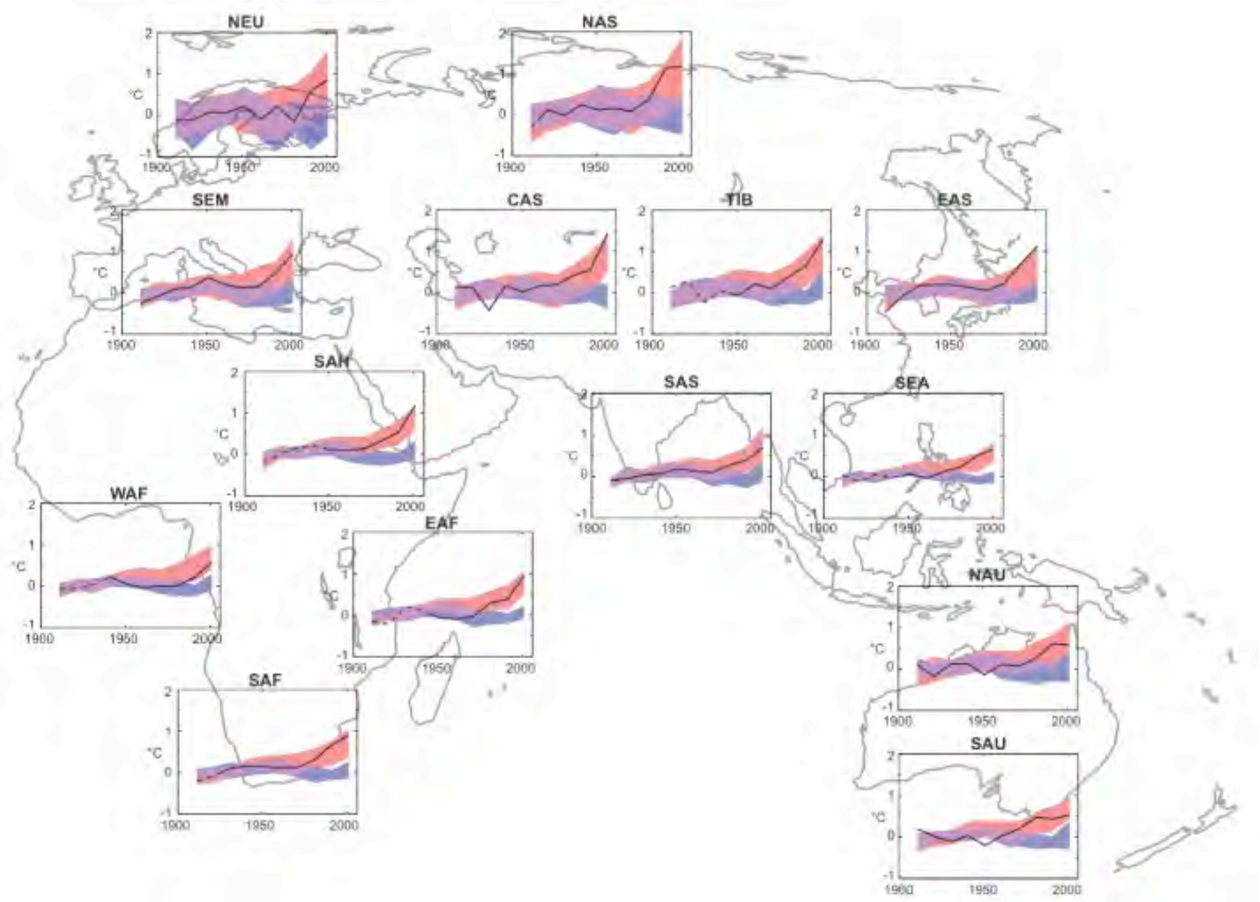
Box 3.1, Figure 1: Link between climate/weather variable probability distribution function (PDF) and associated impacts (A and B), and implication for definition of "climate extremes" (see discussion in text). Note that the PDF of a climate variable is not necessarily Gaussian.



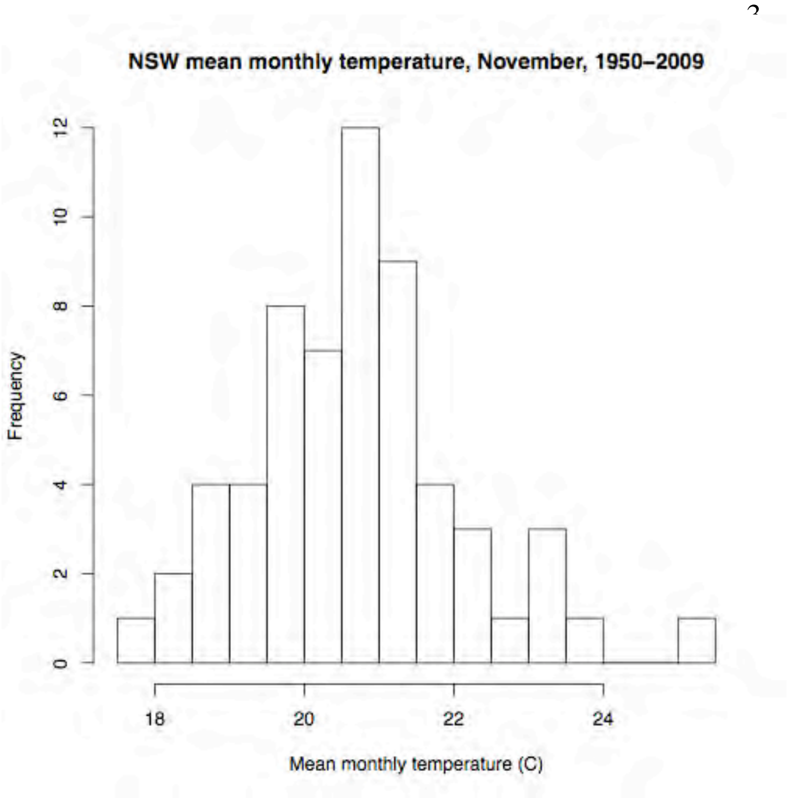
Box 3.1, Figure 2: Link between climate/weather variable PDF and associated impacts under climate change (see discussion in text). Note that the PDF of a climate variable is not necessarily Gaussian.



Box 3.3, Figure 1: Comparison for the Americas of multi-model data set of model simulations containing all forcings (red shaded regions) and containing natural forcings only (blue shaded regions) with observed decadal mean temperature changes (°C) from 1906 to 2005 from the Hadley Centre/Climatic Research Unit gridded surface temperature data set (HadCRUT3, Brohan et al., 2006). The panel labelled GLO shows comparison for global mean; LAN, global land; and OCE, global ocean data. Remaining panels display results for 22 sub-continental scale regions. Shaded bands represent the middle 90% range estimated from the multi-model ensemble. Note that the model simulations have not been scaled in any way. The same simulations are used as in Figure 9.5 of AR4 (58 simulations using all forcings from 14 models, and 19 simulations using natural forcings only from 5 models) (Hegerl et al., 2007). Each simulation was sampled so that coverage corresponds to that of the observations, and was centred relative to the 1901 to 1950 mean obtained by that simulation in the region of interest. Observations in each region were centred relative to the same period. The observations in each region are generally consistent with model simulations that include anthropogenic and natural forcings, whereas in many regions the observations are inconsistent with model simulations that include natural forcings only. Lines are dashed where spatial coverage is less than 50%. From Hegerl et al., (2007).



Box 3.3, Figure 2: Same as Box 3.3, Figure 1 for Europe, Africa, Asia and Oceania. From Hegerl et al., (2007).



FAQ 3.2, Figure 1: The distribution of monthly mean November temperatures averaged across the State of New South Wales in Australia, using data from 1950–2009. Data from Australian Bureau of Meteorology. The mean temperature for November 2009 (the bar on the far right hand end of the Figure) was more than three standard deviations from the long-term mean (calculated from 1950–2008 data).

Chapter 4. Changes in Impacts of Climate Extremes: Human Systems and Ecosystems

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Contents

Executive Summary

This chapter is concerned with how climate and weather events impact on human and ecological systems. This is examined in terms of two distinct types of "extremes": weather and climate extreme events, and extreme impacts on human and ecological systems. Although extreme impacts often follow an extreme event, either extreme can occur without the other. The impacts of weather and climate extremes on humans and ecosystems are a function of exposure, vulnerability and the type and magnitude of the climate extreme. Or put another way the impacts of climate events are mediated by exposure and vulnerability. Extreme impacts may become disasters, especially when the impact is such that local capacity to cope is exceeded.

The chapter looks at observed and projected trends in exposure and vulnerability to, and impacts from, weather and climate events. It does this by sector and by regions. The global costs of these events are estimated and where data exist costs are also estimated for regions.

For practical reasons, both the concept of "extremes" and "rarity" are not amenable to precise definition. Varying spatial and temporal scales, and the almost infinite variation in the attributes of the event in question – such as: duration, intensity, spatial area affected, timing, frequency, onset date, whether the event is continuous or broken such as a continuous drought, and antecedent conditions - mean that it is neither practical nor useful to define extremes precisely. Statistical rarity is determined with respect to time and place, and subject to major changes.

Vulnerability" is defined here to mean susceptibility to harm and ability to recover. Exposures are human and ecosystem tangible and intangible assets and activities in the way of weather or climate events. Assessment of vulnerability and exposure should take account of temporal and spatial scales. Activities far from the site of impact can be seriously impacted. Exposure can be more or less permanent or transitory: for example, exposure can be increased by people visiting an area or decreased by evacuation of people and livestock after a warning. Exposure is a necessary but not sufficient condition for impacts. As human activity and settlements expand in a given area, more will be exposed to and affected by local climatic events.

Observed trends

On the global scale, annual material damage – which represents only part of the human impact - from large weather events, has increased 8-fold between 1960s and 1990s, while the insured damage has risen more (17-fold in the same interval) in inflation-adjusted monetary units. Attempts have been made to normalize loss records for changes in exposure and vulnerability. This allows detection of observed changes in weather hazard rather than the disaster impact. There is no conclusive evidence that anthropogenic climate change has lead to increasing losses, and increasing exposure of people and economic assets is most likely the major cause of the long-term changes in economic disaster losses. This conclusion is subject to debate and depends on the processes used to normalize loss data over time. Different studies use different approaches to normalization, and to handling variations in the quality and completeness of longitudinal loss data. These are areas of potential weakness in the conclusions of longitudinal loss studies, and need more empirical and conceptual effort. A second area of uncertainty concerns the impacts of modest weather and climate events on the livelihoods and people of informal settlements and economic sectors, especially in developing countries. These impacts have not been systematically documented with the result that they are largely excluded from longitudinal impact analysis.

The dramatic expansion of water demand (and water withdrawals) for food production, hygiene, human well-being and industry, including by the power sector, highlights some of the complexities inherent in the weather/exposure interface. These changes have exacerbated both the severity of droughts as well as societal vulnerability to droughts and water deficits.

Projected changes

Human exposure to climatic hazards is increasing. This is to some extent inevitable as population increases, as humanity expands activities in all regions and as resources are increasingly won from more difficult and expensive sources. However, the severity of the resulting impacts of climatic extremes depends on the vulnerability of what is

exposed: on its susceptibility to harm and capacity for recovery. Much data on impacts conflate the effects of exposure with vulnerability as defined in this chapter.

Overall vulnerability appears to be fairly stable, although this general statement conceals a diverse range of trends including areas and groups where the trends are negative.

Higher levels of vulnerability may evolve from the sequence of natural and technological events and the interactions between them. For example, the initial disaster agent may be an invisible contaminant which affects the mental and physical health of those involved, with impacts persisting for years. Such impacts may undermine local resilience for subsequence events.

The impacts of disaster are greatest on poorest households - although this statement conceals important caveats. Poorer households may be resilient, but are rarely covered by insurance or social protection. Disaster impacts lead to income and consumption shortfalls including in education and health, and negatively affect welfare and human development, often over the long term. Poor people typically have higher levels of everyday risk, even without considering the impact of natural hazards. Many of these people are in rural areas, but many are counted among the approximately one billion people worldwide who live in informal settlements – a number growing by approximately 25 million per year.

If people do not have enough to eat in normal times, they may be particularly badly impacted by extreme climatic events. This is especially the case for those entirely dependent on their own produce for their food supply, and those whose cash livelihood depends on their own food crops. Crop-failure is a key driver for rural urban migration, which is expected to be exacerbated by climate change. Increased urbanization may also increase vulnerability to extremes.

The most devastating impacts of climate change related extremes are likely to be associated with extreme sea levels due to tropical and extra-tropical storms, which will be superimposed upon the long-term sea level rise. The impacts will be more severe for deltas, coastal wetlands and small island states, as well as poorer large urban centers. The likely impacts will be mediated by the intrinsic natural characteristics of the local system, and by human activities. One of the more significant economic effects of climate change driven extreme events in coastal areas will be associated with disruption to transportation and especially ports, which may have far-reaching implications for international trade, as more than 80% of global trade in goods (by volume) is carried by sea. Major economic impacts are also expected as a result of disruption to coastal tourism.

Impacts on ecosystems

The impacts of changes in extreme weather and climate events on ecosystems has not been well studied, and extreme events have consequences which are difficult to predict, given that such situations may be unprecedented. Nevertheless, in the Northern Hemisphere the gradual northward and upward movement of the range of many species since 1904 is likely due to the effects of a few extreme weather events on population extinction rates. The variations of the extreme events covers a large array, such as: sudden and transient temperature changes, rapid retreat of sea and lake ice, bouts of abnormally high precipitation or extended droughts, wildfires, the sudden release of water from melting glaciers, insect outbreaks, increases in eutrophication, invasion by alien species, or rapid and sudden increases in disease and slumping of permafrost. These are all examples of events that may have disproportionately large effects on ecological dynamics. Other factors induced by climate change include “false springs,” and the incidence of midsummer frost, which has been directly observed to cause extinction of species.

The Millennium Assessment found that the supply of approximately 60% of the ecosystem services evaluated (15 of 24) was in decline. However, consumption of almost all ecosystem services is increasing. Demand and service flow is increasing as the stock is decreasing. As people have modified ecosystems to increase the supply of provisioning services, these same modifications have led to the decline of regulating ecosystem services, including those responsible for mitigating the hazards of fires and floods.

Regions

In most regions, extremes such as heat waves and wild fires, droughts and floods (fluvial and coastal), are projected to become even more extreme, in terms of frequency and/or intensity. Among the most vulnerable regions to climate extremes are: the Arctic, because of high rates of projected warming on natural systems; Africa, especially the sub-Saharan region, because of low adaptive capacity and increasing hazard; and small islands.

It is estimated that one-third of the people in Africa live in drought-prone areas and are vulnerable to the direct impacts of droughts (famine, death of cattle, soil salinisation). Consecutive dry years with widespread disruption reduce the ability of the affected society to cope with droughts by providing less recovery and preparation time between events. As a result of a multi-year drought, a severe famine developed in the Sahel in 1980s, causing famine and high economic damage. Forest fire danger (length of season, frequency and severity) is very likely to increase in most regions.

Small island states of the Pacific, Indian and Atlantic oceans, are regularly identified as being among the most vulnerable to climate change and climate-related disasters. In the light of current experience and model-based projections, these states, with high exposure of population and infrastructure to risk of sea-level rise and increased storm surge, high vulnerability and low adaptive capacity, have legitimate concerns about their future. Changes to climate means or variability may lead to extreme impacts. Smallness, in both area and economy, renders island countries at risk of very high proportionate losses when impacted by disaster.

Intense precipitation is on the rise in many regions, hence potential for flooding increases. The most flood-prone country on the globe is Bangladesh, where each of the three most extensive floods in the last 25 years inundated more than 60% of the country area. Projections indicate increasing flood risk in Bangladesh.

Summer heat waves have already become increasingly frequent and severe in several continents, with significant economic and human impacts.

In every region there are areas and groups of population that are vulnerable to climate extremes. During the 2003 heat wave, several tens of thousands of additional heat-related deaths were recorded in the increasingly wealthy and ageing societies of southern Europe.

Non-extreme climate events may lead to extreme impacts where system tipping points are reached – such as thermohaline circulation weakening, or collapse of the Amazon forest (‘savannization’). Similarly, oscillations in the Ocean-Atmosphere system are strong regional drivers of climate variability, affecting climate extremes.

Costs of climate extremes and disasters

Economic analysis provides information about the cost and consequences to individual and social welfare of both climatic disasters and the associated adaptation options. Macroeconomic modelling such as input-output models can be used to estimate the impact of disasters on regional or national economies. Disaster loss assessment studies look at specific disasters to estimate the economic, social and environmental impacts of disasters. Expanding the inclusion of environmental values such as ecosystem services in disaster loss assessment is an important area for future work.

The economics of adaptation to extremes is an emerging field. Adaptation studies for developed and developing countries have focused on the costs of adaptation to slower onset climatic changes rather than impacts and damage costs of extremes. Most adaptation studies can be split into four major categories (i) Assessing vulnerability (building on assessments contained in NAPA); (ii) Building institutional capacity (climate information, skilled professionals, and so on); (iii) Piloting adaptation strategies; and (iv) Operational adaptation (needed to cope with new hazards and conditions). The existing estimates of adaptation cost have some weakness in methodology: a) omission of some economic sectors, such as ecosystems, tourism, etc, and b) a lack of consideration for “adaptation deficit” which is relevant to climate proof investment

The experience of disasters and the capacity to adapt varies greatly between developed and developing countries, but also within them. In general, the relationship between development and disaster impacts means a wealthy or richer country relates to a safer country, since a higher income level, governance ability, higher education rate, climate proof investment and insurance system reduce the human cost and economic impact of extreme events and disasters. While the countries with highest income account for more in dollar terms of the economic and insured losses from disasters, a greater portion of GDP and higher fatality rates are generally seen in developing countries, which imposes a greater burden on governments and individuals in those countries. Although there is an absence of any conclusive agreement regarding the long term effects of disasters, it is very likely that poorer developing countries and smaller economies are likely to suffer more from future disasters than developed countries.

Disaster risk management, climate change adaptation and sustainable development are intrinsically linked, and these fields could benefit from increased integration in both theory and practice. Particularly in developing countries with limited adaptation options, initiatives that increase community resilience, such as increasing financial resilience via income diversification and insurance, will have benefits for disaster risk management, climate change adaptation and sustainable development.

4.1. Introduction

Chapter 3 establishes the current status and possible changes in the frequency and intensity of weather and climatic extremes. In doing this they have kept closely to purely natural climatic and weather phenomena. Extremes seen as having a human dimension such as wildfires and erosion are covered in this chapter.

This physical basis provides a picture of climate change and extreme natural events. But it does not by itself indicate the impacts experienced by humans or ecosystems. For some sectors and groups of people severe impacts may result from relatively minor weather and climate events. To understand these impacts triggered by natural events we need to examine the exposure and vulnerability of humans and ecological systems. We also need to clarify what constitutes impacts for whom at what scales.

This chapter examines impacts on human and ecological systems in two ways: the impacts of weather and climate extremes; and secondly, circumstances where severe or extreme impacts are triggered by less than extreme weather events. These two ways of viewing impacts are also examined by regions and sectors – as available data permit,

Activities undertaken as disaster risk reduction may also act as adaptation to climate extremes resulting from climate change, and act to reduce impacts. Strategies to reduce risk from one form of climate extreme may also increase the risk from another. In writing this chapter we have not considered these issues as subsequent chapters are dedicated to adaptation.

4.2. Role of Climatic Extremes in Natural and Socio-Economic Systems

4.2.1. What is "Extreme"?

In the context of this chapter, "extreme" refers to two distinct areas: weather and climate extreme events; and to extreme impacts on human and ecological systems. Although extreme impacts often follow an extreme event, either extreme can occur without the other. The human and ecological impacts of weather and climate events, whether extreme or not, are mediated by exposure and vulnerability. To reiterate the statement on this issue in Chapter 1, Section 1.1.3.2:

> "[T]he explicit recognition of the political, economic, social, cultural, and psychological elements of risk explains the use in this report of the phrase "extreme impacts" in addition to "extreme events" as a way to denote a key aspect of the problem. Depending on the context, physical extremes may or may not bring along extreme impacts; likewise, some extreme impacts may follow from events which in purely physical terms and in isolation from social context would not be defined as extreme. For example, the vast majority of disasters registered annually in particular disaster data bases are not associated with extreme physical events as defined probabilistically (see Section 1.2.X), but many have important and even extreme impacts for local and regional societies (see ISDR, 2009). These data bases include EM-DAT at the Centre for the Epidemiology of Disasters, University of Louvain (CRED, 2008), and the DESINVENTAR data base used by ISDR and others to examine small and medium scale disaster occurrences and "extensive risk" in Latin America and Asia in particular (see ISDR, 2009; Corporación OSSO, 2008)."

The definition is expanded further in Chapter 3, Box 3-1:

> "[Weather and climate events that are not statistically rare] …may also be associated with extreme impacts, in particular if they are linked with the crossing of important thresholds: e.g., a medium deficit in precipitation in a region where mean evapotranspiration has significantly increased, moderately extreme ENSO events, or specific temperature thresholds for human health. Also the accumulation of several events which may each only be mildly extreme can lead to extreme impacts, as is the case for compound events or multiple clustered events (Section 3.1.4 and Box 3.4). Reversely, an extremely rare event may not necessarily lead to major impacts and disasters if it is not associated with some critical thresholds for the impacted systems (either by its nature or because of adaptation). Most global studies of changes in physical extremes do not consider how such extremes are related to actual impacts in the affected regions".

"Extreme events" are atmospheric phenomena, quite separate from human agency.

To quote from IPCC-AR4 (see also Chapter 3, Section 3.1.1.1):

> "[An] Extreme weather event [is an] event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense.
>
> Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season)."

For practical reasons, both the concept of "extremes" and "rarity" are not amenable to precise definition. The varying spatial and temporal scales, dependency on the climate state and context "means that it is not practical nor useful to define extremes precisely" (Chapter 3, Sections 3.1.1.1 and Box 3.1), for example attributes of the event in question vary almost endlessly: duration, intensity, spatial area affected, timing, frequency, onset date, whether the event is continuous or broken such as a continuous drought, and antecedent conditions. Statistical rarity is determined with respect to time and place, and subject to major changes. A rare event in the present climate (100-year flood or 99%-percentile temperature or sea level) may become common under future climate conditions, and cease to be "rare". The impacts of such changes depend on the affected society's capacity to absorb or adapt to new circumstances. From an impacts perspective, one issue is that a percentile approach typically conflates relatively frequent events with the worse case scenarios.

There are however additional dimensions including event sequencing or seriality, compounding and interactions with other trends. This includes events occurring on top of gradual shifts in climate. Extreme events, and sometimes extreme impacts, may occur as a result of normal climate variability such as El Niño and tropical cyclones. Also, extreme events (such as floods, droughts, landslides, wildfires) and consequential extreme impacts may occur as the result of the (extreme) combination of several non-extreme events (also see Section 3.1.4). Such events may be significantly exacerbated by the underlying trends, potentially resulting in non-linear effects, eg a shift to a drier climate with long periods of unusually high temperatures exacerbating drought and water shortages and creating enhanced conditions for major wildfires. There is also the issue of the difference between an absolute extreme such as a day over 40C and a relative extreme such as the 95% percentile). Chapters 1 and 3 examine these dimensions.

Mathematically speaking, extremely high mean annual temperature also belongs to the realm of climate extremes. Among 14 warmest calendar years in the global instrumental observation record, available since 1850, there are 13 years from 1995–2008 (cf., IPCC, 2007, updated). Each of the years 2001–2008 belongs to a set of ten globally warmest years in the history of instrumental record. In the category of average temperature of consecutive 12 months, a recent record was set from July 2006 to June 2007 in several spatial scales (including Europe, and the Northern Hemisphere), cf. Kundzewicz *et al.* (2008).

Not all occurrences of extreme values of hydro-climatic variables cause damage. Some of them may bring benefits, e.g. floods can bring human benefits as with the Nile floods in history and ecological benefits as with the flooding of Lake Eyre in Australia making the adjacent desert bloom (ref. to Kotwicki).

4.2.1.1. Role in Human Systems

Extreme events and impacts have very high profile, are fodder for global media and politics, and people almost everywhere seem motivated to support those suffering severe impacts as a result of weather and climate events. However, greater effort likely goes into preventing the impacts of the more frequent events through adaptation of routine or day-to-day design and management of activities and structures across most aspects of human systems. This includes major roles in religion and spirituality, and in people's minds. While most attention goes on the negative impacts, extremes may also generate economic benefits (eg Handmer and Hillman 2003), and in many cases some social benefits due to community solidarity. As well, the effort that goes into building and otherwise preparing for extreme events may generate much economic activity.

_____START BOX 4-1 HERE _____

Box 4-1. The Collapse of Past Societies.

While we are talking about extreme impacts and the capacity for adaptation, it might be useful to look at why some past societies did not adapt to either climate or environmental changes. In his book Jared Diamond (2005) describes many examples of the collapse or failure of past societies. This can be viewed as an extreme impact and there are no certainties on whether our civilisation will succeed in solving the challenge posed by climate change.

To succeed, a society needs either to anticipate a problem, hence having an excellent understanding of all processes and interactions. Alternatively if a problem was not anticipated, it needs to be perceived (monitoring) and then adapted to through a society's resilience. This requires the political will to attempt to solve the problem. Finally the society must have the know-how, the technology and the resources to solve the problem.

Climate change is a complex issue and shares many of the threats of unsolved problems, such as rational behaviour, tragedy of the commons, irrational behaviour, creeping normalcy and distance between decisions and consequences.

[INSERT FIGURE 4-1 HERE:
Figure 4-1: A path model to societal success or failure.]

_____ END BOX 4-1 HERE _____

In some cases extreme events and extreme impacts have led to major changes in regulations, organisations and policy (eg. Melbourne 2009 Fires, the Indian Ocean 2004 tsunami). In a few cases extreme events may have resulted in dramatic change or abandonment of affected areas (such as the US dust bowl, Egan 2008; parts of inland Australia, Radcliffe 1938), or even the collapse of societies (eg. Diamond 2005). These examples of abandonment and collapse illustrate the need to consider worse case scenarios as well as more frequent and familiar events and impacts.

Historically there are some well known examples of humans undertaking deliberate large scale modification of the natural environment as a direct result of climate extremes. These include the drainage of the Fens in England between the middle ages and 1800s (Ravensdale 1974), the protection of the Dutch coast, and hydraulic engineering feats in the Middle East and Asia (Wittfogel 1957). More generally humans responded to extremes by attempting to manage exposure, for example by avoiding the occupation of areas prone to flooding, and by reducing vulnerability through for example raising dwellings in flood prone areas, or by ensuring food availability in spite of droughts or frosts. The emphasis today appears to be on managing vulnerability as avoiding exposure seems increasingly difficult as humanity spreads into every location.

Today, considerable effort around the world is devoted to preventing, reducing and managing the impacts of extreme events.

Poorer rural areas where livelihoods are heavily or solely dependent on farming or fishing, have housing that is easily damaged by weather events and have limited access to government and commercial services, are particularly susceptible to severe impacts from extreme events and may have limited capacity to recover (XX). Under these circumstances relatively frequent natural events may result in extreme impacts. Response is seen in the pattern of land cropped, in the mix of crops and the preference for low yielding reliable strains over high yielding modern varieties. Extremes force a search for livelihood diversification, dependence on relatives especially remittances from those working elsewhere, and aid funds. Although micro insurance is increasingly available, uptake has been limited (Levin and Reinhard 2007). The livelihoods of the urban poor are not as directly tied to climate, but the security of their housing and well being may be.

Wealthier societies and areas expend much effort to reduce the impact of extremes and to adjust to regular weather events. They do this through design standards for all infrastructure, buildings etc; for example, every road, bridge, large dam and drainage system is designed for a specified flood frequency. Every structure is designed for certain wind speeds, and so on. Wealth and trade are employed to compete globally for scarce resources, such as food, thereby insulating their own societies from the impact of food and other shortages brought on by local extreme events. However, this may simply transfer the negative impacts of an extreme from a wealthy area to a poorer one. More formal approaches to risk transfer have evolved (and continue to evolve through micro insurance and by different approaches to risk analysis for example) in particular through the expanding use of insurance and various forms of post-impact aid both of which transfer the dollar costs of impacts in space and time. Some aspects of the approach in wealthier countries are very energy intensive and produce significant carbon.

In wealthier countries, these building standards and insurance and emergency management systems are calculated explicitly (eg flood frequencies and insurance premiums) or implicitly (eg investments in warning and emergency management systems) against certain levels of risk – where risk is expressed through the occurrence of extreme climatic events, exposure and vulnerabilities. The result is a reasonably high level of insulation against climate extremes. But there are sectors of any country that are very susceptible to the impacts of extremes including agriculture and weather dependent tourism. There are also groups of people such as the homeless and many of the elderly whose circumstances expose them or render them vulnerable to certain climate extremes such as heatwaves and cold. Similar comments may also apply to other groups such as minority ethnic groups, indigenous people and women.

People in poorer countries are generally far less insulated from climate extremes. Many are preoccupied with day to day existence in a context where even frequent events result in severe impacts. Richer countries generally suffer much larger economic losses from disasters when measured in terms of the dollar value of damaged assets and disrupted cash flow, but when measured in terms of proportion of GDP it is poorer countries, especially small countries, that suffer by far the most (*needs updating* XX):

- Honduras, Hurricane Mitch, 1998: 75 percent of GDP
- Turkey, earthquake in 1999: 7-9 percent of GDP
- USA, Hurricane Andrew, 1992: <1 percent of GDP.

Most of the human impact of natural disasters is in the developing world, as shown by the following figures illustrating the dramatic difference between rich and poor countries (IFRC 2001 – from the IFRC database of 2557 disasters from 1991 to 2000):

- HDC (highly developed countries): 22.5 deaths per disaster
- MDC (countries with a medium level of development): 145 deaths per disaster
- LDC (least developed countries): 1,052 deaths per disaster.

Climate extremes, exposure and vulnerability are characterised by dynamism. Major changes to any of these key risk components will have significant implications in terms of both the impact of extreme events and their likely role in human systems. In the short term the main implications are for the groups that traditionally manage disasters and emergencies. They are and likely will be seen as responsible for managing these evolving risks and the increased complexity in impacts they bring.

Changes to underlying climate with extremes superimposed [needs completing].

4.2.1.1.1. Case Study – Sidr (2007) in Bangladesh versus Nargis (2008) in Myanmar

Although 15% of the world tropical cyclones occur in the North Indian Ocean (Reale *et al.*, 2009), they account for 86% of mortality risk (ISDR, 2009). This is due to high population density in exposed areas and poor governance in this region. This vulnerability is particularly of concern given that frequency of tropical cyclones in the North Indian Ocean has registered increasing trends during summer monsoon, which seems to be primarily due to decrease in the vertical wind shear (Muni Krishna, 2009). Intensity trends seems also to be increasing as half of the 8 major tropical cyclones since the last 25 years, were recorded in the three years between 2006 to 2008 (Webster, 2008). Although, data availability and changes in measuring methods makes it difficult to address tropical cyclones trends (Landsea *et al.*, 2006), prudence calls for improving forecasting and mitigation in order to reduce casualties and property damage (Webster, 2008).

Storm surge will be exacerbated in case of climate change leading to more intense tropical cyclones (see Chapter 3) as well as by sea level rise. Storm surges will also be increased by other human activities leading to soil subsidence, such as extraction of oil, gas and water from deltas (Syvitski *et al.*, 2009). Knowing that 80% of victims from Nargis were killed by storm surge and that early warnings do not systematically include storm surge warnings (Webster, 2008), gives cause for concern.

In Bangladesh serious efforts to decrease risk from tropical cyclones were made (Paul, 2009). This was highlighted by the low number of casualties from Sidr in 2007 (Paul, 2009). This contrasts vividly with the outcome of Nargis in Myanmar, where the death toll exceeded 138,000 fatalities making it the eighth deadliest cyclone ever recorded worldwide (Fritz *et al.*, 2009).

To better understand the differences between these two events of similar intensity, it might be useful to compare them as well as their respective contextual situations.

Characteristics and consequences of Sidr and Nargis
Sidr affected Bangladesh in November 2007. Its maximum wind speed reached 245 Km/h (Paul, 2009). Between 8 and 10 million people were exposed/affected (PREVIEW, 2009) and (CRED, 2009). The storm surge reached between 5-6 m (Paul, 2009). The total of reported killed was 4,234 (CRED, 2009). Nargis hit Myanmar on 2 May 2008. Its maximum wind speed reached 235 Km/h (Webster). Between 2 and 8 million people were exposed/affected (PREVIEW, 2009; CRED, 2009). The storm surge reached between 4 m (Webster, 2008). The total of reported killed was 138,366 (CRED, 2009). This summarizes the characteristics of both hazardous events and related contextual parameters.

How Bangladesh Reduced Risk from Tropical Cyclones
Lessons learnt from past exposure
Bangladesh has a significant historical record of large scale disasters. It experienced 15 disasters of more than 1000 casualties since 1960, including the infamous Gorky (April 1991, 138,866 killed) and the November 1970 tropical cyclone which lead to 300,000 deaths (CRED, 2009).

After the devastating cyclone of 1970, the Bangladesh government initiated several structural and nonstructural measures (Paul, 2009). This consists of three major actions:

a) Implementation of an early warning system,
b) Construction of public cyclone shelters and
c) Construction of shelters to provide protection for cattle during storm surges.

Nearly 43,000 volunteers disseminate cyclone warnings among villagers via megaphones and by house-to-house contact. Nearly 4,000 (3,976) shelters were built.

According to field survey (Paul, 2009), 86% of population were aware of the coming of Sidr and 3.2 millions people were evacuated (Paul, 2009).

Environmental features

The 590,000 ha of the Sunderban mangroves and coastal forests proved to be effective barriers to cyclones, during Cyclone Sidr (GOB, 2008). In Bangladesh, a coastal reforestation program was initiated in 1960, covering about 159,000 ha on coastal land, the riverine coastal belt, and abandoned embankments. These plantations reduced the impact of previous cyclones and floods as well as created employment opportunities (GOB, 2008). Their effectiveness as a barrier to cyclones depends on the width of the plantation, the number of stems per unit area, the size of the trees, the effect of branches and the roughness of the land (GOB, 2008).

Cyclone Sidr show that coastal reforestation protects embankments against cyclonic surge and monsoon waves – with the tremendous additional benefit of greatly reducing the impact of the storm surge (GOB, 2008).

Situation in Myanmar, Nargis 2008

Low past exposure to large scale event

Prior to Nargis (2 May 2008), Myanmar had experienced only one disaster with more than 1000 deaths from a tropical cyclone since 1960 (CRED, 2009). As for Nargis, this previous event also occurred in May (10 May 1968). During north hemisphere spring, North Indian Ocean experiences the highest temperature on the planet, along with a low vertical wind shear, conditions which are favorable for the development of tropical cyclones (Webster, 2008).

This was the first time that Myanmar experienced a cyclone of such a magnitude and severity (Lateef, 2009) and "the path of the storm could not have been worse" (Webster, 2008).

It should be noted that several unfavorable conditions were combined for this hazardous event to be transformed into such a large-scale disaster.

Early warning

Early warning was incomplete; the Indian meteorological department has the responsibility to issue warnings for the region, but has no mandate to provided storm-surge forecasts. Myanmar's official forecasts appeared on page 15 in the newspaper The New Light of Myanmar from 29 April to 2 May, suggesting that the media underestimated the threat, thus resulted in insufficient warning to the population (Webster, 2008).

Conclusions

With an estimated $1,500 (2008 estimated) GDPppp for Bangladesh and $1,200 (2008 estimated) for Myanmar (CIA, 2009), these are both very poor countries. However, the difference in poverty cannot explains all. World Bank developed a series of indicators on governance (WorldBank, 2009). It is clear that there are significant differences when ranking the quality of governance between Bangladesh and Myanmar: notably in voice and accountability (31), Rule of Law (22), Regulatory quality (20), Government effectiveness (20). Low governance and especially "voice and accountability" issues were highlighted as one major vulnerability component of human mortality risk to tropical cyclones (Peduzzi, 2009).

While two different hazardous events cannot necessarily be compared, the large discrepancy in resulted casualties recorded appears highly significant.

Despite Nargis being both slightly less powerful and affecting fewer exposed people, as compared with Sidr, the resulting human loss was 32 times higher. Comparison between these two events and countries suggests that awareness (past occurrence of large scale disasters) and improved governance (manifest in improved early warning systems, evacuation plans, infrastructure and the protection of healthy ecosystems) are helping to cope with extreme events.

[INSERT TABLE 4-1 HERE:
Table 4-1: Sidr versus Nargis: general figures (compiled from CRED 2009, Paul 2009, Webster 2008).]

4.2.1.2. Role in Natural Systems [this needs expanding]

Many ecosystems are dependent on extremes for reproduction (fire, floods, wind dispersal), disease control (cold, dry periods), and in many cases general ecosystem health (fires, windstorm etc allowing new growth to replace old).

How these events interact with other trends and circumstances can be critical to the outcome. Floods that would normally be essential to river gum reproduction may carry disease and water weeds; fires that are key to the reproduction of eucalypt species may occur in very dry conditions when plants are stressed by other factors such as drought, disease and competition from weed species.

4.2.2. Complex Interactions between Climate Events, Exposure and Vulnerability

There exist complex interactions between different climatic and non-climatic hazards, exposure and vulnerability that have the potential of triggering complex, scale-dependent impacts.

Human-induced changes in climate and atmospheric systems are believed to be driving changes in climatic variables and corresponding impacts. However, the impacts that climatic extremes have on humans and human-altered environments depends also on several other non-climatic factors (Adger, 2006). This section will explore these factors with reference to extreme precipitation events and flooding. Box 4.2 illustrates some of these issues for wildfires.

Changes in socio-economic patterns are a key component of exposure; in particular population growth is a major driver behind changing exposure and vulnerability (see Barredo, 2009; Downton, Miller and Pielke, 2005). In many regions, people have been encroaching into, and developing, floodplains and other flood-prone areas (Douglas *et al*, 2008; McGranahan, 2007). In these areas both population and wealth are accumulating, thereby increasing the flood damage potential. In many developing countries, human pressure and lack of more suitable and available land often results in encroachment onto urban floodplains. Urbanization, often driven by rural poverty, drives poor people to migrate to areas where effective flood protection is not assured (Douglas *et al*, 2008). Here we see a key tension between climate change adaptation and development; living in these areas without appropriate adaptation is mal-adaptive from a climate change perspective, but this may be a risk people are willing to take, or over which they have limited choice, considering their economic circumstances (Wisner et al., 2004). Furthermore, there is often a deficient risk perception present, stemming from an unjustified faith in the level of safety provided by flood protection systems and dikes in particular.

Economic development and land-use change can also lead to changes in terrestrial systems (hydrological systems and ecosystems). Land-cover changes induce changes in rainfall-runoff patterns, which can impact on flood risk. Deforestation, urbanization, reduction of wetlands and river regulation (channel straightening, shortening, embankments) change the conditions under which precipitation becomes runoff by reducing the available water storage capacity (Few, 2003; Douglas *et al*, 2008). These transformations can also contribute to loss of natural inundation areas (e.g. elimination of floodplains, wetlands, and wash-lands) and infiltration capacity. Furthermore they increase the proportion of impervious area (roofs, yards, roads, pavements, parking lots, etc.) and the value of the runoff coefficient. As a result, water runs off faster to rivers or the sea, and the flow hydrograph has a higher peak and a shorter time-to-peak (Few, 2003; Cheng and Wang, 2002; Douglas *et al*, 2008), reducing the time available for warnings and emergency action. In mountainous areas, developments extending into hilly slopes are endangered by landslides and debris flows, triggered by intense rains. These changes have resulted in less extreme rain leading to serious disaster.

Similarly, droughts should not be viewed as exclusively physical or natural phenomena. Their socio-economic impacts may arise from the interaction between natural conditions and human water use, which can be conceptualized as a combination of supply and demand factors. Human activities (such as over-cultivation, overgrazing, deforestation) have exacerbated desertification of vulnerable areas in Africa and Asia. Desertification is seen where soil and bio-productive resources became permanently degraded. An extreme example of a man-made, pronounced, hydrological drought comes from the Aral Sea basin. Due to excessive and non-sustainable water withdrawals from the tributaries (Syr Darya and Amu Darya), their inflow into the Aral Sea has shrunk dramatically (Micklin, 2007).

The climate change impact on sectors depends not only on changes in the characteristics of climate-related and sector-relevant variables, but also on such system properties as: pressure (stress) on the system, system management (also organizational and institutional aspects), and adaptive capacity. Climate change is likely to challenge existing management practices by contributing additional uncertainty (McGranahan, 2007).

Possible interactions of several hazards may also be an increasing threat, where cascading and conjoint effects result in increasing threats to society. Hazards may trigger others (as heat wave and drought may trigger wildfire) or exacerbate their effects. Temperature rise leads to permafrost thaw, reduced slope stability and damage to buildings. The triggering effect is also likely to be size-dependent. Several climatic hazards, independent of each other, have the potential to affect the same area, even in one season. Examples of conjoint hazards are: heat wave, drought and wildfire. A severe drought following a high intensity wildfire, which itself would most likely occur during a period of heat and water stress, will likely have major negative impacts on post-fire ecological recovery. In case of cascading hazards, one hazard influences other hazards, e.g. intense precipitation leads to flash flood, land slides and infrastructure damage – collapse of bridges, roads, and buildings, and interruption of power and water supplies. It is worthwhile to note that cascading system failures (e.g. among infrastructure) can happen rapidly and over large areas due to their interdependent nature.

_____ START BOX 4-2 HERE _____

Box 4-2. Evolution of Climate, Exposure, and Vulnerability – The Melbourne Fires, 7 February 2009.

The Melbourne fires demonstrate the inter-relationships between the climate and weather related phenomena of drought, extreme heat and wildfire. Together these created the conditions for major uncontrollable wildfires. A rapidly expanding urban-bush interface and valuable infrastructure provided the values at risk and the potential for disaster. There was a mixture of natural and human sources of ignition, showing that human agency can be key to such fires.

Saturday 7 February 2009 saw the worst fire weather conditions in the Australian state of Victoria's history. The maximum temperature in Melbourne's CBD was 46.4 degrees centigrade, with temperatures elsewhere up to 2.5 degrees higher than the previous record at that site (Karoly 2009). There were very strong winds, and record low relative humidity of 5% (although humidity data in Australia is limited) (Karoly 2009).

With climate change, such hot dry conditions are very likely to become more frequent. (See for example: Goldammer and Price, 1998; Kitzberger, Swetnam *et al.*, 2001; Flannigan, *et al.*, 2005; Reinhard, *et al.*, 2005; Hennessy, *et al.*, 2006; Moriondo, *et al.*, 2006). Alexander and Arblaster (2009) report increases in temperature extremes and a significant increase in the length of heatwaves in Australia over the period 1957-1999.

The day of the fires came after 12 years of the state's hottest and longest drought (Trewin and Vermont, 2010). Over this period, average annual rainfall was 10-13% below any previous twelve-year period (before 1997) and the rainfall total was 10-20 % below the long-term average (Royal Commission 2009, Chapter 1 footnote 5). There had been a string of the hottest years on record in the last decade, a 35 day dry spell with no measurable rain for Melbourne through January 2009, topped off by the most severe heatwave on record the week before (Trewin and Vermont, 2010). These antecedent conditions were likely, even in the absence of the extreme conditions on February 7, to result in non-linear effects in terms of enhanced conditions for wildfires (REF). The heat and drought resulted in very low fuel moisture content of about 3-5% on February 7. Under these conditions, any fuel will burn vigorously.[1] Fire weather severity is measured by the Fire Danger Index (FDI) which ranges from 0-100. On

February 7 the FDI was predicted to be well over 160 +. The actual index appears to have been as high as 189 or higher in some areas (Royal Commission 2009, Figure 1.6).

[INSERT FOOTNOTE 1 HERE: Fire energy is measured in watts per linear meter of fire front. Forest fires during February 7th reached intensities of 80,000 KWm-1 (Royal Commission 2009, Fig 1.6), similar to levels seen during the 1983 Ash Wednesday fires in Victoria (Packham 1992). Unless the fires are very small at less than a hectare, suppression action by direct attack has an upper limit around the 4kW m -1 in forest fuels (Luke and McArthur, 1978; Buckley 1994). The use of aerial fire fighting appliances has little impact on this figure (Rawson and Rees 1983, Loane and Gould 1986, Robertson et al 1997, McCarthy 2003, Royal Commission 2009, Fig 1.6). Asset protection may nevertheless be effective, and was effective for many on February 7 (REF).]

In addition to the 173 lives lost as a direct result of the fires (State of Victoria, 2009), losses included the destruction of over 2000 homes, losses of livestock and crops, damage to infrastructure, and business premises.

Like most major Australian cities, Melbourne is expanding into former farmland and bush areas, with little or no regard for the fire risk. This is complemented by a flow of people moving into rural areas. Regional Victoria is projected to grow by 400,000 people by 2031, mostly in coastal and inland areas near Melbourne and major regional centres (State of Victoria, 2005). Many of those moving into rural areas are in search of lifestyle changes (Burnley and Murphy, 2004; Costello, 2007), the bush environment, and housing affordability (Berry, 2003; Costello, 2009), with the latter likely to be the most powerful driver.

Under the climate conditions experienced in the area north of Melbourne ten years ago, the area was considered low fire risk (REF). However, the desiccation of formally mixed wet and dry sclerophyll forests and moist south facing slopes by the drought and heat changed the area into a high risk area (CITE). The increased exposure includes infrastructure, town centres and livelihoods, much of which was damaged or destroyed in the Melbourne fires. Significant essential infrastructure serving much of Melbourne is also located in or near the fire affected areas, including water supply catchments, electricity supply corridors and telecommunications facilities.

In addition to these fixed exposures, there is an increasing amount of transitory exposure due to people visiting the areas for recreation and tourism. The exposure of people can be changed rapidly by people, and their movable assets, moving into or out of the areas at risk.

A range of factors influenced people's *susceptibility to harm* from the Melbourne fires. Many people were not physically or psychologically well-prepared for the fires, and this influenced the level of loss and damage they incurred. Levels of physical and mental health also affected people's vulnerability. Many individuals with ongoing medical conditions, special needs or other impairments struggled to cope with the extreme heat and were reliant on others to respond safely (Whittaker *et al*., 2009). *Capacity to recover* in a general sense is high for humans and human activities through insurance, government support, private donations, and NGOs.

Capacity is highly variable for natural ecosystems. Some areas show strong regrowth while others show little, demonstrating the impacts of very high intensity fires and ongoing drought. The long drought, habitat destruction through urban expansion and the spread of feral species had reduced ecosystem resilience in the fire affected areas.

______ END BOX 4-2 HERE _____

4.2.2.1. About Permafrost

Climate change in the Russian Arctic degrades permafrost, such that vast territories of tundra may be replaced by taiga. From epidemiological point of view these changes could expand the habitat of rodent species that carry infections. Changes in water circulation and rising water temperatures could also increase diseases in marine mammals and fish [Climate change impact . . .]. Climate warming leads to permafrost degradation, the 40-80-cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost (Sherstyukov, 2009). Changes in permafrost damage the foundations of buildings and disrupt the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10-12% in 20-25 years, with permafrost borders moving 150-200 km northeast (Anisimov *et al*., 2004).

An apartment building collapsed following melting permafrost in the upper stream of the Kolyma river, and over 300 buildings were severely damaged in Yakutsk as a result of retreating permafrost. More than 50% of buildings in Pevek, Anderm, Magadan, and Vorkuta have also been damaged [Anisimov, Belolutskaya, 2002, Anisimov, Lavrov, 2004]. Approximately 250 buildings in Norilsk industrial district had significant damage caused by deteriorating permafrost and approximately 40 apartment buildings have been torn down or slated for demolition [Grebenets, 2006.]. Permafrost degradation along the coast of the Kara Sea may lead to intensified coastal erosion, which moves the coastline back by 2-4 meters per year [Anisimov, Lavrov, 2004]. This coastline retreat poses considerable risks for coastal population centres in Yamal and Taymyr and on other littoral lowland areas. Climate refugees may emerge if climate change significantly damages housing. Refugees from climate change have already appeared in Arctic territories of the United States (Shishmaref) and Canada (Tuktyaktuk). Coastal destruction has also become a problem for residents of Inupiat and on the island of Sarichev.

4.2.2.2. Case Study – Forest Fires in Indonesia

Old-growth forests are usually carbon sinks. As old-growth forests steadily accumulate carbon for centuries, they contain vast quantities of it. They will lose much of this carbon to the atmosphere if they are disturbed, so carbon-accounting rules for forests should give credit for leaving old-growth forest intact (Luyssaert *et al*., 2008).

Severe drought in moist tropical forests provokes large carbon emissions by increasing forest flammability and tree mortality, and by suppressing tree growth (Ray *et al*., 2004). The frequency and severity of drought in the tropics may increase through stronger El Niño Southern Oscillation (ENSO) episodes, global warming, and rainfall inhibition by land use change (Ray *et al*., 2004).

Under drought conditions, fires in Indonesia is a disproportionate contributor to GHG from biomass burning, although human are igniting the fires, drought acts as trigger for fire occurrence and large fires events were found to occurred when precipitations drop below 609mm (Field *et al*., 2009). In Indonesia and PNG, formation of peatland during Holocene lead to the accumulation of potentially 70 Pg of carbon, this is comparable to the carbon stored in aboveground vegetation in the Amazon or to 9 years of contemporary global fossil fuel emissions. Drought episode, forest fires, drainage for rice fields and oil palm plantations are drying the peatlands which are then more vulnerable to fires (Van der Werf *et al*., 2008).

Over Amazonian forest, forest subjected to a 100-millimeter increase in water deficit lost 5.3 megagrams of aboveground biomass of carbon per hectare. The drought had a total biomass carbon impact of 1.2 to 1.6 petagrams (1.2 × 1015 to 1.6 × 1015 grams). Amazon forests therefore appear vulnerable to increasing moisture stress, with the potential for large carbon losses to exert feedback on climate change (Phillips *et al*., 2009).

If drought is a trigger to deforestation via forest fires, conversely, deforestation in the Amazon and Cerrado was found to increase the duration of the dry season in these regions (Costa and Pires, 2009).

A drastic deforestation scenario would result in a severe restructuring of land–atmosphere dynamics (see Figure 4-2), partially explaining why most AGCMs have predicted weakened water fluxes as a result of extensive deforestation (D'Almeida *et al*., 2007).

[INSERT FIGURE 4-2 HERE:
Figure 4-2: Schematic representation of the hydrological impact of different extents of clearing (in dark gray) in Amazonia. The horizontal water vapor flux transfers moisture into the region and in the case of (a) no deforestation, this flux is sustained by precipitation recycling, maintaining high indices of rainfall. Areas of (b) local deforestation are too small to affect rainfall, but runoff increases and evapotranspitation decreases. Areas of (c) regional

deforestation are large enough to influence circulation, strengthening convection and potentially increasing rainfall. A (d) basin-wide deforestation scenario would impose a severe decline on evapotranspiration and then on precipitation recycling, weakening the hydrological cycle in Amazonia as a whole. Source: (D'Almeida et al., 2007).]

In an inventory of over 225,000 trees of tropical forest in Panama, (Chave *et al*., 2003) conclude that small trees were providing much of the biomass increase, however 60% of the biomass is included in 1% of the larger diameter trees, while 97.6% of the smaller diameter trees include less than 15% of the biomass. In this view, slowing deforestation, combined with an increase in forestation and other management measures to improve forest ecosystem productivity, could conserve or sequester significant quantities of carbon (Dixon *et al*., 1994).

4.2.3. How Do They Impact on Humans and Ecosystems?

4.2.3.1. Concepts and Human Impacts

The impacts of weather and climate extremes on humans and ecosystems are a function of exposure, vulnerability and the type and magnitude of the climate extreme. Or put another way the impacts of weather and climate extremes are mediated by exposure and vulnerability. This is occurring in a context where all three components, the social and political elements of exposure and vulnerability, and the physical element of climate, are highly dynamic and subject to continuous change. For instance nowadays, a less extreme rain (compared with past records) may lead to a very serious flooding disaster. Reduced volumes of natural water storage – floodplains, wetlands; and increase in ground imperviousness and in runoff coefficient may cause higher river runoff corresponding to a given rainfall. Furthermore, the value of wealth accumulated in the affected area has grown as well.

Changes to exposure and vulnerability can be considered as adaptive action. For example, migration away from high hazard areas [hazard is here defined as the climate event following EMA and ISDR – cf Chapter 1] reduces exposure and the chance of disaster and is also an adaptation to increasing risk from climate extremes. Similar remarks could be made for changes to building regulations and livelihoods, among numerous other examples. However, in this chapter impacts are assessed without reference to possible adaptive action, and the chapter does not attempt to distinguish between adaptive action as a result of climate change and the management of exposure and vulnerability for existing hazards.

“Vulnerability” is defined here to mean susceptibility to harm and ability to recover (EMA, but cf Chapter 2). This chapter will also refer to “resilience” (developed in an ecological context by Holling, 1978; in a broad social sustainability context by Handmer and Dovers 2005; and by the Resilience Alliance, Adger, 2006), which emphasises the positive components of resistance or adaptability in the face of an event and ability to cope and recover. The language of “resilience” is often seen as a positive way of expressing a similar concept to that contained in the term “vulnerability” (Handmer, 2003).

4.2.3.2. Disaster

Extreme impacts on humans and ecosystems can be conceptualised as “disasters” or “emergencies”. Charles Fritz (1961: 655) was probably the first to articulate a definition in the research and policy literature: Disasters are “…uncontrollable events that are concentrated in time or space, in which a society undergoes severe danger and incurs such losses … that the social structure is disrupted and the fulfillment of all or some of the essential functions .. is prevented.”

Many contemporary definitions are similar, emphasising either that a disaster results when the impact is such that local capacity to cope is exceeded or that it severely disrupts normal activities. For example, the Center for Research on the Epidemiology of Disasters (CRED) in Brussels, Belgium has four criteria for a disaster including two suggesting external aid: “declaration of a state of emergency” and “call for international assistance”. The Australian Emergency Management Glossary emphasises disruption: “A serious disruption to *community* life which threatens or causes death or injury in that community and/or damage to property which is beyond the day-to-day capacity of the prescribed statutory authorities …" (EMA Glossary Manual 03 – 1998).

Despite the emphasis in official definitions, in practice:

> "Disasters are subject to numerous definitions: to an investment bank they mark an investment opportunity, in the same genre as investing in shares; they are research opportunities; and the livelihoods of many NGOs and professionals are built on them. To governments, disasters offer the opportunity to legitimise themselves, to parade their power by mobilising resources, and to empathise with the victims by offering sympathy and assistance. Seen like this, disasters are social, political or economic phenomena, not visitations by some force external to human control or as a result of calculated engineering risk" (Handmer and Dovers 2007).

Quarantelli (1998) examines this question from a variety of perspectives. There is a significant literature on the definitional issues which include factors of scale and irreversibility. Major issues with the standard definitions include:

- The focus on "events" which can obscure the social processes leading to disaster and also imply a definition framed by the natural event rather than by the impacts
- Reliance on "external assistance" which may discriminate against well prepared or otherwise resilient communities and sectors
- The idea of "returning to normal", as often it will not be possible to return to what was there before (Handmer and Hillman 2004), and it may not be desirable (REF)
- Some disasters may be difficult to define in space or time, droughts are an example, as are complex sequences of events referred to as complex unbounded problems (Handmer and Dovers 2007)
- As what constitutes or causes a disaster (or emergency) is dependent on a wide range of circumstances and varies greatly by location this chapter does not adopt a quantitative approach.

As stated at the start of this section, impacts require both exposure to the climate event and a susceptibility to harm by what is exposed.

Exposure can be conceptualised as human and ecosystem tangible and intangible assets and activities (including services) exposed (as in the way of) to the weather or climate event and its energy. Time and space scale is important. Exposure can be more or less permanent or transitory: for example, exposure can be increased by people visiting an area or decreased by evacuation of people and livestock after a warning. Exposure is a necessary but not sufficient condition for impacts. As human activity and settlements expand into a given area, more will be exposed to and affected by local climatic events. Most population increase is in poor countries that are disproportionately affected by climatic hazards. In addition, many newly occupied areas were previously left vacant precisely because they are hazardous, especially on the fringes of or in poorly-built infill in ever-growing urban areas. This is best seen in areas prone to flooding, landslides and industrial pollution, now occupied by squatters or informal settlements; and at the other end of the wealth spectrum, by those seeking environmental amenity through coastal canal estates, riverside and bush locations, areas that are often at greater risk from floods and fires.

For what is exposed to be subject to significant impacts from a climate event, there must be vulnerability. Vulnerability is composed of (i) susceptibility of what is exposed to harm (loss, damage) from the weather event, and (ii) its capacity to recover. For example, those whose livelihoods are weather dependent or whose housing offers limited protection from weather events will be particularly susceptible to harm, while those with limited capacity to recover include those with limited personal resources for recovery or with no access to external resources such insurance or aid after an event, and those with limited personal support networks. Knowledge, alternative livelihoods, health and access to services of all kinds including emergency services and political support help reduce both key aspects of vulnerability.

Refugees and those driven into marginal areas as a result of violence are often the most dramatic examples of people vulnerable to the negative effects of natural events, cut off from coping mechanisms and support networks (drawn from Handmer and Dovers 2007). Reasons for the increase in vulnerability associated with warfare include destruction or abandonment of infrastructure (transport, communications, health, education) and shelter, redirection of resources from social to military purposes, collapse of trade and commerce, abandonment of subsistence farmlands, lawlessness and disruption of social networks (Levy and Sidel 2000). The proliferation of weapons and minefields, the absence of basic health and education and collapse of livelihoods can ensure that the effects of war on vulnerability to disasters are long lasting. These areas are also characterized by an exodus of trained people and an absence of inward investment.

4.2.3.3. Impacts on Ecosystems

Even without considering the role of climate change, ecosystems are under significant threats. We are currently experiencing the sixth major biodiversity extinction and the first from human origins (Wilson, 1999). The current rate of species extinctions on Earth is 100 to 1,000 times greater than the natural rate and is accelerating (May et al., 1995)

Climate change will exacerbate the impacts from habitat fragmentation. Increased frequency of large-scale disturbances caused by extreme weather events will cause increasing gaps and an overall contraction of the distribution range, particularly in areas with relatively low levels of spatial cohesion (Opdam and Wascher, 2004). On the basis of mid-range climate-warming scenarios for 2050, 15–37% of species in their sample of regions and taxa will be ‘committed to extinction’ (Thomas, 2004). Rapid climatic change or extreme climatic events are expected to alter community composition. (Walther et al., 2002).

Extreme events can cause mass mortality of individuals and contribute significantly to determining which species occur in ecosystems (Parmesan et al., 2000). Drought plays an important role in forest dynamics, driving pulses of tree mortality in the Argentinean Andes (Villalba and Veblen, 1997), North American woodlands (Breshears and Allen, 2002; Breshears et al., 2005), and in the eastern Mediterranean (Körner et al., 2005b). Hurricanes can cause widespread mortality of wild organisms, and their aftermath may cause declines due to the loss of resources required for foraging and breeding (Wiley andWunderle, 1994). Greater storminess and higher return of extreme events will also alter disturbance regimes in coastal ecosystems, leading to changes in diversity and hence ecosystem functioning. Saltmarshes, mangroves and coral reefs are likely to be particularly vulnerable (e.g. Bertness and Ewanchuk, 2002; Hughes et al., 2003). [see also IPCC, AR4, GWII, 4.2.1]

Other anthropogenic changes are such as land use, nitrogen deposition, pollution and invasive species, habitat losses, and over harvesting (Vitousek et al., 1997; Mack et al., 2000; Sala et al., 2000; Hansen et al., 2001; Lelieveld et al., 2002; Körner, 2003b; Lambin et al., 2003; Reid et al., 2005; Wilson, 1999).

4.2.3.4. Phenomenon Induced by Climate Change that Lead to Impacts on Ecosystems

The impacts of change in frequency/intensity of extreme event are much less studied (Easterling et al., 2000), as most of the studies covers response to continuous climate change. Still, in the Northern Hemisphere the gradual northward and upward movement of the range of many species since 1904 is likely due to the effects of a few extreme weather events on population extinction rates (Parmesan, 2006). Extreme events have consequences which are difficult to predict, given that such situations may be unprecedented. The variations of the extreme events covers a large array, such as insect outbreaks, sudden and transient temperature changes, rapid retreat of sea- and lake ice, bouts of abnormally high precipitation or extended droughts, wildfires, the sudden release of water from melting glaciers, and slumping of permafrost are examples of stochastic events that may have disproportionately large effects on ecological dynamics (Post et al., 2009). Other factors inducted by climate change include “false springs,” and midsummer frost, which has been directly observed to cause extinction of species (Easterling et al., 2000).

In both the Canadian Rockies (Luckman, 1994) and European Alps (Bugmann and Pfister, 2000) extreme cold through a period of cold summers from 1696 to 1701 caused extensive tree mortality. Heat waves such as the recent 2003 event in Europe (Beniston, 2004; Schär et al., 2004) have both short-term and long-term implications for vegetation, particularly if accompanied by drought conditions. The December 1999 ‘storm-of-the-century’ that affected western and central Europe destroyed trees at a rate of up to ten times the background rate (Anonymous, 2001). Loss of habitat due to hurricanes can also lead to greater conflict with humans. For example, fruit bats

(*Pteropus spp*.) declined recently on American Samoa due to a combination of direct mortality events and increased hunting pressure (Craig et al., 1994). [see also IPCC, AR4, GWII, 4.2.1]

In Monteverde preserve (Costa Rica), 40% of the 50 local amphibian species have become extinct since 1983 (Easterling et al., 2000). A detailed analysis of four frog species showed that extinction followed a series of drastic population declines in each of three severe droughts associated with El Niño events (Easterling et al., 2000).

Climatic extremes appear to influence juvenile survival in large mammals species, primarily during winter (Milner et al., 1999). Single extreme temperature event influence the adult sex of turtle, as this is determined by the maximum temperature experienced by the growing embryo (J. J. Bull 1980 and F. J. Janzen 1994 cited in (Easterling et al., 2000).

Potential solutions

For species where no adaptation is possible, the only option is to mitigate the level of GHG released in the atmosphere so that Earth temperatures do not exceed the tolerance of the species.

For species which can migrate, reducing the impacts from climate change on species would request a shift in strategy from protected areas towards landscape networks including protected areas, connecting zones and intermediate landscapes. A static approach of establishing isolated reserves surrounded by a highly unnatural landscape is not an effective strategy under a climate change scenario (Opdam and Wascher, 2004).

4.2.4. Lists of Hazards in Terms of Hazards (Climate Extremes), Sectors and Systems, and Regions

[possible three-dimensional matrix maybe electronic as a product of the chapter]
[awaiting completion of other sections]

[INSERT TABLE 4-2 HERE:
Table 4-2: Factors to be considered in this section.]

4.2.5. Detection and Attribution of Climate Change Impacts *(also see Section 4.6.5)*

Detection and attribution of climate change impacts can be defined and used in way that parallels the well-developed applications for the physical climate system (IPCC 2010). Detection is the process of demonstrating that a system affected by climate has changed in some defined statistical sense, without providing a reason for that change (IPCC 2007). Attribution is the process of establishing the most likely causes, natural or anthropogenic, for the detected change with some defined level of confidence.

The IPCC Working Group II Fourth Assessment Report found, with very high confidence, that observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases (IPCC 2007). Further, data since 1970 shows that anthropogenic warming is likely (66-90% probability of occurrence) to have had a discernible influence on many physical and biological systems. Two fundamental approaches have been used in detection and attribution of climate change impacts: direct attribution and joint attribution.

Direct or 'single-step' attribution comprises assessments that attribute an observed change within a system to an external forcing based on explicitly modeling the response of the variable to external forcings and drivers (IPCC, 2010). Few such studies have been carried out and are limited to cases where the affected system and its interaction with climate are either relatively well modeled (e.g. hydrological cycle; Barnett et al., 2008) or reasonably described empirically (e.g. area burnt by forest fires; Gillett et al., 2004).

Joint or 'multi-step' attribution comprises assessments that attribute an observed change in a system to a change in climate or environmental conditions, and the change in climate or environmental conditions is separately attributed to external forcings and drivers (IPCC, 2010). Using this approach, changes within many physical (e.g. glaciers, river flow, coastal erosion) and biological systems (e.g. polar bear behavior, spring flowering, bird migration, grape harvests) have been linked to regional warming and, in turn, the warming attributed primarily to increasing anthropogenic greenhouse gas concentrations (Rosenzweig et al., 2008 and references therein).

In the case of weather and climate extremes and rare events, attribution to anthropogenic forcing is complicated by the fact that any such event might have occurred by chance in an unmodified climate. For example, a change in the frequency of rare heatwaves may not be detectable. A solution to this problem is to look at the risk of the event occurring, rather than the occurrence of the event itself (Stone and Allen, 2005). For example, human-induced changes in mean temperature have been shown to increase the likelihood of extreme heat waves (Stott et al., 2004).

There is considerable evidence that economic losses from weather-related disasters are increasing but reliably attributing these losses to climate change is proving difficult (Miller et al 2008). Some studies claim that a climate signal can be found in the records of disaster losses (Malmstadt et al., 2009; Schmidt et al., 2009). However, others argue that the increasing losses can largely be accounted for by underlying societal trends - demographic, economic, political, social - that shape our vulnerability to impacts (Pielke et al, 2005; Bouwer et al., 2007). Attempts have been made to normalize loss records for changes in exposure and vulnerability. This allows detection of observed changes in weather hazard rather than the disaster impact. In general, no long-term trends can be found in normalized losses due to extreme wind events (Pielke et al 2008; Miller et al 2008). Trends in flood losses can be explained largely by socio-economics drivers, including increasing occupancy of flood-prone areas and the increasing value of assets exposed to flood (Pielke and Downton, 2000; Barredo, 2009). However, other studies point to increased incidence of extreme precipitation as a potential cause (Changnon, 2009; Chang et al., 2009).

There is no conclusive evidence that anthropogenic climate change has lead to increasing losses, and increasing exposure of people and economic assets is most likely the major cause of the long-term changes in economic disaster losses. This conclusion depends on the processes used to normalize loss data over time. Different studies use different approaches to normalisation, and to handling variations in the quality and completeness of longitudinal loss data. These are areas of potential weakness in the conclusions of longitudinal loss studies and need more empirical and conceptual effort. A second area of uncertainty concerns the impacts of modest weather and climate events on the livelihoods and people of informal settlements and economic sectors, especially in developing countries. These impacts have not been systematically documented with the result that they are largely excluded from longitudinal impact analysis.

4.2.6. Comment on 4°C Rise

A 4°C rise in itself is not an extreme event, but it may result in much more significant change in frequency/magnitude of various extreme events than climate change of around 2 degrees. Since some studies (ex. Betts et al. (2009)) suggest that the likelihood of a 4°C rise in latter half of this century is not negligible, we also need to be prepared for these significant changes. Knowledge of impacts expected under +4°C world and of response strategies to such impacts have been emerging recently.

The international climate policy target of the community (cf. Copenhagen Accord, 2009) is to restrict global warming to less than 2°C. This level is often held as a relatively safe limit beyond which the humans should not pass, even if already a 2 ºC warming brings risks to unique and threatened systems, risks of extreme events, and distribution of impacts (cf. IPCC TAR SPM, Schneider, 2009). The ‘burning embers’ diagram (see Figure 4-3) illustrates the reasons for concern and urgency of threats as a function of temperature. In order to achieve this goal, major, and effective, global mitigation efforts would be required, which should start sufficiently early (Hulme and Neufeldt, 2010).

[INSERT FIGURE 4-3 HERE:
Figure 4-3: Burning embers (Schneider, 2009).]

The Intergovernmental Panel on Climate Change assessed five reasons for concern in terms of societal, economic and natural damage that would be caused by climate change (TAR, 2001). Updates to judgements about the thresholds at which such damages might occur revised the thresholds downwards Smith et al., 2009).

Impacts can be related to global mean temperature increase and the risks of large adverse changes and the reasons for concern greatly increase for higher levels of temperature increase (TAR, AR4, Schneider, 2009; see Figures 4-4 and 4-5). A scenario without effective mitigation (business-as-usual), can be symbolically denoted as 4°C warming. This entails high risk in all categories of reasons for concern, including risk of extreme weather events, distribution of impacts, the aggregate economic impacts and the risk of large-scale continuities. A 4°C warming may lead to dangerous effects of climate change in the context of Article 2 of the UN FCCC.

[INSERT FIGURE 4-4 HERE:
Figure 4-4: Illustrative examples of global impacts projected for climate changes (and sea-level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts, dotted arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left hand side of text indicates approximate onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of Special Report on Scenarios (SRES) scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. (Source: IPCC AR4 WG2 SPM, 2007).]

[INSERT FIGURE 4-5 HERE:
Figure 4-5: Illustrative examples of global impacts projected for climate change (Stern, 2006).]

An illustration of impacts of 4°C warming is the average global number of people affected by 100-year floods per year evaluated as 544 million, i.e. over 2.5 times more than for 2°C warming (projected to be 211 million), cf Hirabayashi and Kanae (2009) and Kundzewicz et al. (2010).

According to Arnell (2009), 15% of land worldwide that is currently suitable for agriculture would become unproductive at a +4°C world. On the other hand, suitable land would shift north, to regions such as Siberia, which is currently covered in forest. Globally, extension of suitable area for crop production is larger than loss of present suitable area even with climate change of 4°C warming. However, regarding regional impacts, extension of suitable area for crop production cannot be expected even with small degree of climate change in Southern and Eastern Africa while loss of present suitable area will monotonically increase and reach more than 30 % at +4°C world.

Rahmstorf (2009), employing a semi-empirical approach he has developed, projected future sea level rise of 1 – 1.3 meters at 4 ºC above preindustrial temperatures by 2100, much higher than the projected sea level rises reviewed in IPCC-AR4.

Adaptation to 4°C warming, globally, would be very difficult and costly, and many adverse effects cannot be avoided. Projections of impacts and adaptation for a number of sectors and systems show that effective climate policy combines mitigation and adaptation, in order to constrain adverse impacts at a manageable level (Hulme and Neufeldt, 2010).

4.3. Observed Trends in Exposure and Vulnerability

4.3.1. Climate Change Contributes to and Exacerbates Other Trends

On the global scale, annual material damage from large weather events has increased 8-fold between 1960s and 1990s, while the insured damage has risen even stronger (17-fold in the same interval), in inflation-adjusted monetary units. Material damages caused by natural disasters, mostly weather and water-related have increased more rapidly than population or economic growth, so that these factors alone may not fully explain the observed increase in damage. The loss of life has been brought down considerably (Mills, 2005).

The drought and flood losses may have grown due to a number of non-climatic factors, such as increasing water withdrawals effectively exacerbating the impact of droughts, decrease in storage capacity in catchments (urbanization, deforestation, sealing surfaces, channelization) adversely affecting both flood and drought preparedness, increase in runoff coefficient, and mushrooming settlements in floodplains around urban areas.

On average, 2% of agricultural land has been lost to urbanization per decade in the European Union. Van der Ploeg et al. (2002) attributed the increase in flood hazard in Germany to climate (wetter winters), engineering modifications, but also to intensification of agriculture, large-scale farm consolidation, subsoil compaction, and urbanization. The urbanized area in West Germany more than doubled in the second half of 20th century.

Since water resources have always been distributed unevenly in space and time, people have tried to reduce this unevenness and smoothen the spatial–temporal variability. Regulating flow in time can be achieved by storage reservoirs, capturing water when abundant and releasing it when it is scarce, while regulating flow in space can be achieved via water transfer. Dams and reservoirs have been built for millennia, but most large dams have been constructed since the second half of the twentieth century. Now, the total volume of reservoirs exceeds 6000 km^3, whereas the total water surface area reaches 500 000 km^2. In result of dams and reservoirs, the natural runoff regime of many rivers has been considerably altered (cf. Vörösmarty, 2002).

Until a century ago, when the number of people on Earth was relatively low, and the human impact on water resources (using and drinking freshwater) was generally insignificant, and local rather than global in impact. The situation dramatically changed as water withdrawals strongly increased due to dynamic population growth (from 1.65 billion in 1900 to 2.56 billion in 1950 and 6 billion in 1999, and 7 billion in 2010) and socioeconomic development driving improvements in living standards, including more water-intense diet and improving hygiene. Freshwater, which is a necessary condition of life and a raw material used in very high volumes in virtually every human activity, has become increasingly scarce in many places and times. Water use has risen considerably in the past hundred years, at a pace twice as fast as the relative population growth (Kundzewicz, 2008). There has been a dramatic expansion of water demands (and water withdrawals) for food production, hygiene and human well-being, and industry, including by the power sector. This exacerbated the severity of droughts and societal vulnerability to droughts and water deficits.

In much of the developed world, the societies are ageing, hence more sensitive to weather extremes, such as heat wave.

It is now reasonable to assume that climate stationarity does not exist, and the past is not really a key to the future, as we are entering a situation with no analogy in past records (Milly et al., 2008). This is of vast importance for design rules. What used to be a 100-year river flow (exceedance probability of 0.01) is projected to be exceeded less frequently over some areas and more frequently over other areas. In the latter case, if the existing defences are designed for a 100-year flood, they do not have to be strengthened in order to maintain the same level of protection. However, in the areas where the level of past 100-year flood is projected to be exceed more frequently (e.g. every 50 years, on average), there will be a need to strengthen and heighten the existing protection system, in order to maintain the same protection level (Kundzewicz et al., 2010).

*4.3.2. **Observed Trends in Exposure** (demographic, to all climatic extremes, and to specific types of hazard)*

4.3.2.1. Human Exposure to Tropical Cyclones by Region

Description

These figures are extracted from the PREVIEW Global Risk Data Platform (PREVIEW, 2009), methodologies and extract of the data were published in the Chapter 2 of the UNISDR 2009 Global Assessment Report (Peduzzi, 2009). These figures are taking only the hazard exposure assuming constant hazard. We will need to review these figures, once we receive the inputs from SREX Chapter 3 team on the envisaged increase of intensity/frequency of the hazards.

4.3.2.1.1. Exposure for tropical cyclones by region and by class of intensity

The figures are yearly average human exposure (computed over 32 years) to tropical cyclones winds by Saffir-Simpson classes. Total yearly average human exposure to tropical cyclones in 1970, 1990 and 2010 is of respectively 45, 62 and 77 millions. This is due to increase in population living in exposed areas and assuming hazard is constant. With change in intensities (and or) frequencies of the cyclones, these figures will probably change in the future. Details of exposure by class of Saffir-Simpson and year are provided in the three tables below for 1970, 1990 and 2010.

[INSERT TABLE 4-3 HERE:
Table 4-3: Yearly average human exposure to tropical cyclones in 1970 (Peduzzi et al., 2009).]

[INSERT TABLE 4-4 HERE:
Table 4-4: Yearly average human exposure to tropical cyclones in 1990 (Peduzzi et al., 2009).]

[INSERT TABLE 4-5 HERE:
Table 4-5. Yearly average human exposure to tropical cyclones in 2010 (Peduzzi et al., 2009).]

This could be presented as graphs or maps, however, we will wait for final figures on hazards changes to produce the graphs. GDP exposure is also available.

4.3.2.1.2. Exposure for floods by region

Only catchment areas bigger than 1000 km^2 are considered in this analysis (Peduzzi *et al.*, 2009).

[INSERT TABLE 4-6 HERE:
Table 4-6: Yearly average human exposure to floods in 1970, 1990, and 2010 (Peduzzi et al., 2009).]

4.3.3. Observed and Projected Trends in Hazards and impacts, Changing Frequency of Different Intensities, and New Locations Affected *(to be discussed with Chapter 3)*

4.3.3.1. Coastal Systems: Natural and Human

Coastal systems are among the world's most vulnerable areas to climate extremes. Superimposed upon the intrinsic long-term trends of coastal systems (due e.g. to tectonic movements (Vött, 2007) or sediment auto-compaction (Massey et al., 2006)), are impacts by both marine (e.g. sea level rise, storm surges and waves) and terrestrial (e.g. precipitation/run-off) extremes of increasing frequency and intensity extremes (e.g. Lozano et al., 2004; Wang et al., 2008; The Copenhagen Diagnosis, 2009; Steffen, 2009; Fiore et al., 2009; Ruggiero et al., 2010), the effects of which on the system morpho-sedimentary dynamics are controlled by inherent environmental change thresholds (Nicholls et al., 2007). Moreover, as the size/permanence of coastal communities and infrastructure has increased very significantly over recent decades, the ability of coastal systems to respond has decreased; thus the exposure of coastal communities/assets has increased (Lenton et al., 2009). Although predictions of exposure to climatic extremes are required at decadal to century scales (e.g. Viles and Goudie, 2003), most of the available data/models are based on studies at either millennium (e.g. Masters, 2006; Nott et al, 2009) or annual (e.g. Quartel et al., 2008; Greenwood and Orford, 2008) or even storm event (e.g. Callaghan et al., 2008) scales. There have been several attempts to develop global coastal hazards data bases (Gornitz, 1991; Vafeidis et al., 2008), as well as methodologies/tools to assess the vulnerability of coastal systems to sea level rise/extreme events (e.g. Bernier et al., 2007; Purvis et al. 2008; Hinkel and Klein, 2009), but further work is urgently required (Nicholls et al., 2007). Coasts comprise several sedimentary environments and landforms, such as beaches, seacliffs, deltas, back-barrier environments (estuaries and lagoons), saltmarshes and mangroves, seagrass meadows and coral reefs. Each of these environments is characterised by different vulnerability to climate change-driven hazards (Table 4-7).

[INSERT TABLE 4-7 HERE:
Table 4-7: Coastal systems: summary table of observed and predicted exposure trends.]

4.3.3.1.1. Natural systems [to be shifted to Chapter 3?]

Beaches and seacliffs

Beaches, i.e. the low-lying coasts built on unconsolidated sediments, are among the most morphologically dynamic environments, being controlled by complex process-response mechanisms that operate in several temporal and spatial scales (Van Rijn, 2003). Beaches provide dynamic protection to the coastal environments they front (e.g. back-barrier systems and cliffs), as well as an increasing human infrastructure and other economic assets. Beach erosion can be differentiated into: (i) long-term erosion, i.e. irreversible retreat of the shoreline position, due to sea level rise and/or negative coastal sedimentary budgets (Nicholls et al, 2007) that force either landward migration of the beaches or drowning; and (ii) short-term erosion, caused by storms and storm surges, which may not necessarily result in permanent shoreline retreats, but may create large-scale devastation (Niedoroda et al., 2009). Beach erosion is already a major global problem, being very significant along the southeastern (Zhang et al., 2004), the Gulf (Morton et al., 2004) and California (Hapke et al., 2006) US coasts, in China (Cai et al., 2009), in India (Dwarakish et al., 2009), in Canada (Forbes et al., 2004; Lantuit and Pollard, 2008), the Pacific island atolls (Dickinson, 2004), the Atlantic, Mediterranean and Baltic European coasts (Eurosion, 2004) and the Black Sea (Stanica and Panin, 2009). The projected sea-level rise (SLR) (IPCC, 2007; Rahmstorf, 2007; Richardson et al., 2009) will likely exacerbate beach erosion (Velegrakis et al., 2009), although the local timing and extent of beach morphological response will depend also on other factors, such as the beach and inner continental shelf physiography (Callaghan et al., 2008), the ‘normal’ and storm coastal hydrodynamics and sediment dynamics (Stockdon et al., 2007; Pye and Blott, 2008; Nott et al., 2009), the coastal sediment availability and budgets (Battiau-Queney et al., 2003; Dan et al., 2009) and the presence of adjacent back-barrier sediment traps (Nicholls et al., 2007); these factors can significantly modify beach response to sea level rise. In addition, changes in the intensity and/or frequency of storms (see Section 3.4 and e.g. Ruggiero et al., 2010) and/or other climatic extremes such as heavy precipitation events and river floods (e.g. The Copenhagen Diagnosis, 2009) may be even more important than sea level rise in determining future beach morphodynamics (e.g. Brunel and Sabatier, 2009; Barnard and Warrick, 2010)). Finally, large climatic modulations (e.g. ENSO and NAO), may also have significant impacts, as they promote larger frequency of high energy events (Nicholls et al., 2007).

Seacliff erosion, which may have significant socio-economic impacts (Del Río and Gracia, 2009), can usually be attributed to extreme events, being controlled by both storm surges and storm wave attack (Sallenger et al., 2002; Hall et al., 2008), as well as strong rainfall (Greenwood and Orford, 2008; Young et al., 2009). Erosional processes appear to be dependent on the cliff lithology and geotechnical properties (Collins and Sitar, 2008), the characteristics (height and steepness) of the storm waves (Hansom et al., 2008), as well as the volume of fronting protecting beaches (Walkden and Dickson, 2008); modeling experiments have shown that seacliff retreat will be exacerbated by sea level rise (Nicholls et al., 2007).

Deltas

Deltaic environments are influenced by all climatic changes/extremes affecting riverine and marine processes (e.g. changes in the precipitation/run-off, sea level rise and storms), as they are controlled by the combined action of riverine, wave and tidal processes (Restrepo and Lópe, 2008; Poulos et al., 2009). In addition, deltas are commonly impacted by the effects of human development, such as sediment starvation due to river management schemes and engineering works at their mouths (Stanica et al., 2007; Mikhailov and Mikhailova, 2008; Simeoni and Corbau, 2009), which may affect significantly the exposure and resilience of the deltaic coasts to climatic changes (Sabatier et al., 2009). Deltas are particularly sensitive to climate change, as they are commonly characterized by large Relative Sea Level Rise (RSLR) due to the combination of eustatic sea-level rise, deltaic sediment auto-compaction, groundwater/hydrocarbon extraction-induced subsidence and diminished sediment supply. A study involving 40 deltas, representing all major climate zones and which collectively drain 30% of the Earth's landmass and 42% of global terrestrial runoff has found RSLRs ranging between 0.5 to 12.5 mm yr^{-1}, with the diminishing fluvial sediment supply/deposition being the most important determinant of the result (Erickson et al., 2006). Extreme events, particularly storm surges (Ullmann et al., 2007; McKee Smith et al, 2010) pose a particular threat to deltaic environments, especially the larger systems which are considered as hotspots of vulnerability (Coleman et al., 2005; Nicholls et al., 2007).

Estuaries and lagoons

Estuaries and lagoons are particularly sensitive systems to climate change. Climate-driven changes and extreme events with regard to freshwater run off can affect water residence time, nutrient delivery, stratification, salinity and primary productivity (Nicholls et al., 2007; Gamito et al., 2010). Sea-level rise generally translates into landward transgression of estuaries (Pethic, 2001) and leads to higher relative water levels and salinity, affecting hydrodynamics (Simionato et al., 2004) and sediment dynamics (Shennan et al., 2003), the distribution of tidal wetlands (Doyle et all, 2009) and biodiversity (Ellison, 2005). Water level changes can increase the risk of flooding, particularly if combined with high river flows, storm surges, and the effects of water management schemes (Le et al., 2007). Increases in the intensity of tropical cyclones and other storms combined with sea level rise, are likely to increase substantially the exposure to flooding (Karim and Mimura, 2008), as well as alter estuarine sediment dynamics and biogeochemical processes (Paerl et al., 2001). With regard to human-induced changes, it has been shown that their effects on estuarine morphodynamics can, in some cases, be greater than those of the sea level rise itself (Chust et al., 2009), although modeling exercises suggest that, in the long term, the morphological development will be mostly controlled by the estuarine physiography and the ability of external sediment supply to meet the increasing sediment demand of the system (Reeve and Karunarathna, 2009).

Coastal wetlands, coral reefs and seagrasses

Coastal wetlands (saltmarshes, mangroves) are controlled by long-term sea-level changes. Modelling of coastal wetlands (McFadden et al., 2007) indicates large global losses by 2080, depending on the rate of sea level rise, wetland losses are likely to be most severe in micro-tidal and/or sediment starved coasts, as wetlands in meso- and macro-tidal settings and/or in areas with increased sedimentary inputs are considered to be better equipped to deal with changes in sea level (Cahoon et al., 2006). At the same time, as wetlands have the potential to attenuate storm surges and waves (Neumeier and Amos, 2006; Wamsley et al., 2010), their loss will probably result in further increase in storm surge and wave exposure.

Saltmarshes are common features of temperate coastlines; they are graded landward from salt, to brackish, to freshwater assemblages. Climate change will force changes in the hydrological, hydrodynamic and sediment dynamic regime, the frequency/intensity of extreme events and the biogeochemical conditions, with the effects considered to be more pronounced in brackish and freshwater marshes, (Nicholls et al., 2007). Saltmarshes accrete both organic and inorganic sediments. While feedbacks between vegetation growth and sediment deposition tend to promote morphological equilibrium under constant sea level rise rates, recent observations/modeling suggest that changes in the rise rates may induce marshland losses; it has been demonstrated that organic sediment accumulation is non-linearly related to both inorganic sediment supply and sea-level rise rates and that carbon accumulation increases with the rise rate until a critical threshold, which terminates the process and forces marsh drowning (Mudd et al., 2009). In addition, climatically-driven groundwater level fluctuations can also affect saltmarsh elevation and resilience (Cahoon et al., 2010). Simulation of the saltmarsh response to future rise in sea levels (100 year predictions) suggests that under low sea level rise scenarios, there may be marsh progradation, whereas under rapid rise rates vegetation zones are likely to transgress landward (Kirwan and Murray, 2008). With regard to the effects of storm surges and waves, accretion rates in micro-tidal, wave dominated marshes have been found to respond to short-term sea level changes, whereas those in macro-tidal, wave protected coasts mostly to long-term changes (Kolker et al., 2009). Finally, the propagation of surges and the impinging wave energy onto saltmarsh areas during storms have been found to be sensitive to sea level, with both surge propagation and wave heights being greater in areas with increased RSLR (McKee Smith et al., 2010).

Mangrove forests, found in sub-tropical and tropical coasts, may show both positive and negative responses to climate change, depending on site-specific factors (Saenger, 2002). Based on the available evidence, relative sea level rise may be the greatest threat to mangroves, as most mangrove sediment surface elevations do not appear to be able to keep pace (Gilman et al., 2008). Although mangrove accretion rates can be much higher than the average global sea level rise rates (commonly up to 5 mm/yr, see Saenger, 2002), mangal coasts are generally characterized by relatively rapid RSLR (Cahoon et al., 2003); this may result in either a mangrove transgression onto adjacent wetlands, as is the case in the US Gulf coast (Doyle et al., 2009) and southeast Australia (Rogers et al., 2005), or drowning and/or die-offs (Williams et al., 2003; van Soelen et al., 2010). Precipitation/run off has also been shown to be a significant factor, with a significant positive relationship found with landward mangrove expansion (Eslami-Andargoli et al., 2009). Finally, strong tropical cyclones can have negative effects on both the sedimentary structure (Cahoon et al., 2003) and the spatial distribution of mangroves (Paling et al., 2008).

Coral reefs are subject to a variety of impacts in relation to climate change (James and Crabbe, 2008) and, above some critical thresholds, they could be subjected to increased strain, or even collapse ((Veron et al., 2009), introducing particular concerns for the fate of small islands on the rim of atolls (Dickinson, 2004; Nicholls et al., 2007). Sea level rise itself appears to present a minor threat to coral reefs, as they have been found to be able to adapt effectively if not subjected to other environmental stresses (Hallock, 2005). Tropical cyclones and high energy storms, however, can inhibit typical reef growth (Montagionni, 2005) by decreasing coral recruitment (James et al., 2008) and/or result in reef destruction (Yu et al., 2004; Lugo-Fernandez and Gravois, 2010) with the reef debris deposited as reef talus at their lee (Harris and Heap, 2009) or as ridges to adjacent beaches (Nott and Hayne, 2001; Woodroffe, 2008). Other climatically-driven changes to the hydrodynamic regime of coral reef platform islands, such as changes in the direction of storm wave approach, may also result in significant morphological changes of the coral reef-beach systems (Kench et al., 2009).

Seagrasses appear to be in decline in many coastal areas, due mainly to human-induced interferences (e.g. seagrass bed removal for tourism purposes, see Daby, 2003), with the situation expected to deteriorate further due to climate-forced changes in the salinity and temperature of coastal waters, sea levels, atmospheric and dissolved CO2 concentrations and ultraviolet irradiance (Short and Neckles, 1999). Changes in coastal sediment dynamics can also affect seagrasses; studies on the effects of sediment deposition/erosion on shoot mortality, plant size, growth, biomass and density have shown species- and size-dependent sediment burial or erosion thresholds (Cabaço et al., 2008). Extreme precipitation and/or heat events (floods, droughts and heat waves) have also been observed to affect estuarine seagrass ecology (Cardoso et al., 2008). Finally, tropical cyclones can also affect the community structure of seagrass meadows, with the effects dependent on growth-form; solid, deeply anchored root–rhizomes or rhizoid systems, combined with a flexible or modular above-ground structure have been found to better resist perturbations by hurricanes and storms (Cruz-Palacios and van Tussenbroek, 2005).

4.3.3.1.2. Human systems

Although coastal inundation due to SLR (and/or RSLR) will certainly be a very significant problem for coastal landforms and coastal populations, activities, infrastructure and assets in Low Elevation Coastal Zones (LECZs, i.e. coastal areas with an elevation less than 10 m above present MSL, see McGranahan et al., 2007), the most devastating impacts are likely to be associated with extreme sea levels due to tropical and extra-tropical storms (e.g. Ebersole et al., 2010), which will be superimposed upon the long-term SLR. The impacts are considered to be more severe for deltas, coastal wetlands and Small Island States (Love et al., 2009), as well as large urban centers at the low end of the international income distribution (Dasgupta et al., 2009). The extent/distribution of exposure in each particular coastal area/urban center will be controlled by the intrinsic natural characteristics of the system (e.g. the occurrence/distribution of coastal wetlands that may attenuate surges, see Wamsley et al., 2010) or human-induced changes such as land reclamation (Guo et al., 2009).

With regard to the economic impacts of extreme events on coastal areas, a recent study by Nicholls et al. (2008) has assessed the asset exposure of 136 port cities with more than one million inhabitants (in 2005). They demonstrated that large population segments are already exposed to coastal inundation (~40 million people or 0.6% of the global population) due to a 1-in-100-year extreme event, while the total value of exposed assets was estimated as 3,000 billion US dollars (~ 5% of the global GDP in 2005). By the 2070s, population exposure was estimated to triple, whereas asset exposure could grow tenfold to ~ 35,000 billion US dollars, with the exposure growth being more rapid in developing countries; these estimations, however, do not account for the potential construction of effective coastal protection schemes. Lenton et al. (2009), who included tipping point scenarios, such as the effects of the partial collapse of the Greenland and West Antarctic Ice Sheets (Rahmstorf, 2007; Richardson et al., 2009), estimated a significant increase, by 2050, in the asset exposure in the same 136 port megacities to ~28,200 billion

US dollars. They also estimated a very substantial increase in the exposure of coastal population to inundation (see Table 4-8).

[INSERT TABLE 4-8 HERE:
Table 4-8: Current and future population exposure in low elevation coastal zones.]

One of the most significant effects of climate change driven extreme events on the infrastructure/services in coastal areas will be associated with transportation and especially with ports, key-nodes in international supply-chains; this may have far-reaching implications for international trade, as more than 80% of global trade in goods (by volume) is carried by sea (UNCTAD 2009a). Transportation will be affected by extremes in temperature and precipitation, storm surges and rising sea levels; while all modes of transportation are vulnerable, exposure and impacts will vary, e.g. by region, mode of transportation, as well as location/elevation and condition of any transport infrastructure (National Research Council, 2008; UNCTAD, 2009b). Coastal inundation may damage terminals, intermodal facilities, freight villages, storage areas and cargo and disrupt intermodal supply chains and transport connectivity (see Figure 4-6). These effects would be of particular concern to Small Island Developing States (SIDS), whose transportation facilities are almost all located in the LECZ (UNCTAD, 2009b; for further examples, see Love et. al. (2009)). One of the most detailed studies on the potential impacts of climate change on transportation systems was carried out in the US Gulf Coast. According to the study, RSLR of ~1.2 m could permanently inundate more than 2,400 miles of roadway, over 70% of port facilities, 9% of the rail miles operated and 3 airports, while more than 50% of interstate and arterial roads, 98% of port facilities, 33% of rail miles operated and 22 airports in the US Gulf coast would be affected by a ~5.4 m storm surge (CCSP, 2008). Experts at a recent UNCTAD Èxpert meeting highlighted the need for an increased focus on responding to the challenges posed by climate change, and the development of appropriate adaptation responses (UNCTAD 2009b). It should be noted that the International Association of Ports and Harbours (IAPH), representing some 230 ports in about 90 countries which handle over 60% of the world's sea-borne trade and nearly 90% of the world's container traffic has recently tasked its Port Planning and Development Committee to undertake the necessary studies (IAPH, 2009).

[INSERT FIGURE 4-6 HERE:
Figure 4-6: Freight handling port facilities at risk from storm surge of 5.5 and 7.0 m in the U.S. Gulf coast (CCSP, 2008).]

Housing in coastal areas will also be severely affected by climate change-driven extremes (e.g. Maunsell, 2008). A recent study (Lloyd's, 2008) has considered flood risk for coastal properties at a number of locations around the world due to SLR and storm surges and, at one location, changes in land use. The case-studies suggest that unless adaptation measures are taken, a 0.3 m sea level change could significantly increase the average loss exposure of high-risk coastal properties, even in coastal areas with well-maintained flood-defenses.

Tourism has, over recent years, increasingly become synonymous with beaches ((Phillips and Jones, 2006), a coastal landform that is under an increasing threat of erosion (see Section 1); island/archipelago destinations, one of the main focuses of the "sun and beach" mass tourism, are going to be particularly exposed to erosion (Bardolet and Sheldon, 2008; Schleupner, 2008). In addition to beach erosion, inundation of tourist infrastructure in coastal areas due to climate extremes (e.g. Snoussi et al., 2008; Dwarakish et al., 2009), salinization of the groundwater resources due to RSLR, land reclamation and overexploitation of coastal aquifers (e.g. Alpa, 2009) as well as changing weather patterns (Hein et al., 2009) will pose additional stresses to the industry. There are also expected to be shocks relating to tourist flow changes due to adjustments in consumption preferences, as well as regional income reallocation; these shocks are predicted to affect regional economies and lead to unevenly-distributed economic losses (Berrittella et al., 2006). Nevertheless, the potential impacts on the tourist industry will depend also on tourists' perceptions of the coastal destinations (e.g. of destinations experiencing beach erosion) which, however, can not be easily predicted (Buzinde et al., 2009).

4.3.3.2. Case Study – Long-Term Records of Flooding in Western Mediterranean [move to Chapter 3?]

In Mediterranean countries, flooding episodes and prolonged periods of drought constitute normal hydrological phenomena that society has to cope with. Floods are the natural risk with the greatest economic and social impact that can be generated in a short space of time (hours or days), although, if we are dealing solely with economic losses, drought impact in crops and losses in hydroelectric power generation can lead to higher economic costs (Pujadas, 2002). Flood and drought damages in Europe have been rising since 1980s despite of flood protection structures in rivers and flow regulation by dams (Munich Re, 2001). In addition, recent catastrophic floods have eventually became the largest events on the systematic record (most river flow measurements recording less than 50-60 years), being interpreted as a result of climate change. Documentary and palaeoflood (sedimentological and botanical) archives can provide a century-to-millennia reference of flood response (magnitude and frequency) to climate variability, from which interpreted recent and projected flood hazards. Moreover, long-term records provides a suite of examples about society coping with floods impacts from which learn to modify and adapt societal behaviours, and reasonable hypothesis for flood hazards to be expected for the next fifty years.

In terms of flood-producing atmospheric conditions, the western Mediterranean shows three distinct regions: (1) Central and Western Iberian Peninsula, (2) Mediterranean coast of Spain and Western Mediterranean Sea; (3) Corsica, Sardinia and the western coast of Italy (Douguédroit and Norrant, 2003). Central and Western Iberian Peninsula rivers respond to winter floods produced by Atlantic cyclonic systems brought by zonal circulation, highly correlated with winter (DJF) negative mode of the North Atlantic Oscillation (NAO) index (Trigo *et al.*, 2004). The Tagus river (Central-western Iberian Peninsula) documentary and palaeoflood (geological) records show an abnormally high frequency of large floods during distinct periods, namely at 1150-1290 1590-1610, 1730-1760, 1780-1810, 1870-1900, 1930-1950 and 1960-1980 (Benito *et al.*, 2003a,b; see Figure 4-7). Flood discharge estimates show that the largest floods happened in the 12-13th Century, late 19th Century and 20th Century periods. The largest historical flood peak discharges since AD 1500 (Benito *et al.*, 2003, 2008) occurred during negative winter (DJF) North Atlantic Oscillation index, as reconstructed by Luterbacher *et al.*, (2002). In large Iberian Atlantic rivers, flow regulation by dams since 1950s have decreased the frequency for floods of discharge less than 10-year return intervals (<8,000 m^3s^{-1}), but events of higher return intervals have occurred with a similar frequency (if not higher) than historical records (e.g. 1978, 1979, 1989, 1996, and 1998 floods). Decreasing risk perception on annual to decadal floods have led to occupation and urbanization of former inundation areas, with the subsequent increase on damages by multidecadal floods, producing important social and economical impacts in the Lisbon region. Climate model simulations suggest that NAO shows a weak positive response to increasing amounts of carbon dioxide, although none of the models are able to reproduce decadal trends as strong as observed in NAO index from 1970–1995 (Osborn, 2004; Stephenson *et al.*, 2006). Therefore, flood hazard projection on rivers highly correlated with NAO index remains still highly uncertain, although recent occurrence of large floods point out to be maintained over the next decades (Benito et al., 2005).

[INSERT FIGURE 4-7 HERE:
Figure 4-7: Temporal distribution of frequency of large floods.]

Flooding in the Mediterranean coast of Spain and France is associated with heavy rainfall induced by mesoscale convective systems (MCSs), and typically occurs during autumn months (SON). Flood records over the last 500 years show an intense climatic variability, characterised by periods of increased frequency of torrential rains, reflected in catastrophic flooding, as well as by an increased frequency of prolonged droughts (flood-rich and flood-poor periods). This abnormal behaviour usually lasted for 30 or 40 years (see Figure 4-7), being the periods of 1580-1620 and 1840-1870 the ones where the highest flooding severity was registered (Barriendos and Martín Vide, 1998). It appears that these periods recorded more frequent floods as compared to the 20th Century (Guilbert, 1994; Coeur, 2003, Luterbacher *et al.*, 2006), although similar extreme peak discharges were attained in some rivers by 20th Century floods. These recent catastrophic floods were ranked as the largest peak discharge but extended flow records from documentary and palaeoflood data over the last millennia shows a repeated past occurrence of such extreme floods (e.g. 2002-flood in Gardon river, Sheffer et al., 2008; 1973-flood in the Guadalentín-Segura basin Benito et al., 2009; and 1971-flood in the Llobregat River, Thorndycraft et al., 2005, 2006; and 1982-flood in Segre River, Thorndycraft et al., 2005). There is, however, an important and rising factor of vulnerability in most Mediterranean rivers, mainly cause by urbanization, and increasing sensitivity to natural hazards of modern society, that makes historic floods a highly destructive and intolerable modern flood hazard. The increase on population and extensive occupation of the Mediterranean region since 1980s contribute to the perception of increasing flood risk (CITE). However, it is also important to state that climate conditions with strong seasonal temperature variations is expected to favor cyclogenesis whenever inflows of cold air enter the Mediterranean, specially in autumn (Llasat and Puigcerver, 1994).

In the western coast of Italy, Corsica, and Sardinia flood producing mechanism are related with meridional circulation associated with Mediterranean depressions, northern troughs reaching the Mediterreanean, or depressions coming from northern Africa (Piervitali and Colacino, 2003). In the Tiber River (Central Italy) extreme events were particularly frequent at 1400-1500 and 1600-1700 (Camuffo *et al.*, 2003; see Figure 4-7). These two periods were characterised by an increased frequency of great and severe winters and under these circumstances the cyclogenesis was enhanced by a greater contrast between the seawater and the colder air masses (Camuffo *et al.*, 2003). The former was documentary described as a wet period, which included the Spörer Period of minimum solar activity (1416-1534). The periods 1000-1400, 1500-1600 and 1700 onwards show a very low flood frequency, which was further reduced after the works had been done in the 19th century. In Italy the Spörer Minimum was a period that had been particularly hit by extreme meteorological events and overflows (Camuffo and Enzi, 1994; 1995a,b; Brazdil *et al.*, 1999; Glaser *et al.*, 1999). Extreme floods exceeding the 16 m stage (<2600 m^3s^{-1}) at Ripetta landing (16545 km^2) were not constant in time: four flood above 18 m (<3400 m^3s^{-1}) took place in a period of only 80 years during the 1530-1606 (Calenda *et al.*, 2005) at the starting of the Little Ice Age, intriguingly a period of reported low flood frequency by Camuffo *et al.* (2003). Recent flooding is difficult to evaluate in the context of climate change due to river regulation structures, with the largest flooding exceeding 2000 m^3s^{-1}, occurring in 1937 (2750 m^3s^{-1}), 1937 (2750 m^3s^{-1}), 1923 (230 m^3s^{-1}), 1947 (2300 m^3s^{-1}), 1929 (2050 m^3s^{-1}), 1976 (2050 m^3s^{-1}). In the December 2008 flood (12.55 m ca. 1400 m^3s^{-1}), large economic impacts demonstrated an increased flood vulnerability of Rome region despite of decreasing flood hazard by flow regulation at basin scale (Natale and Savi, 2007). In the 20th Century, flood events exceeding 1400 m3s-1 prior to 1970s occurred at an average frequency of 7 times per decade, whereas after 1970s decreased to about 5 events.

Regarding droughts, it is more difficult to define distinct periods due to their complex spatial distribution, but in the Iberian Peninsula were clearly more frequent in the middle 16th (1540-1570) and 17th centuries (1625-1640), less severe in 1750-1760, as well as between 1810-1830 and 1880-1910 (Barriendos, 2002). The existence of periods with flood frequency together with droughts should also be mentioned. To date only one such period is known, between 1760 and 1800, but its effects spread throughout much of Western and Central Europe, with a clear impact on agricultural production and even social crises in different countries (Barriendos and Llasat, 2003).

4.3.4. Observed Trends in Human Systems and Sector Vulnerability to all Climatic Extremes and to Specific Types of Hazards

4.3.4.1. Vulnerability Trends

Section 3.3 shows that human exposure to climatic hazards is increasing. This is to some extent inevitable as population increases, as humanity expands activities in all regions and as resources are increasingly won from more difficult and expensive sources. However, the severity of the resulting impacts of climatic extremes depends on the vulnerability of what is exposed: on its susceptibility to harm and capacity for recovery. Much data on impacts conflate the effects of exposure with vulnerability as defined in this chapter.

Although all of humanity is exposed to some extent to climatic hazards and all have some vulnerability, there are some key factors in people's day to day existence that work at a very general level to undermine people's ability to manage their climate risks including their capacity to cope and recover from loss. Such factors include:

- War and chronic violence
- Being poor especially in rural areas due to livelihood insecurity
- Urban poor in informal settlements
- Living in a poor country or a small island country
- People without sound emergency support

- Areas with degraded ecosystems.

One indicator of trends in vulnerability may be provided by the impacts of climatic hazards (with appropriate normalisation of the data), although as these are impact data they may indicate more about the natural phenomenon and exposure rather than vulnerability. Care is needed in ascribing impact trends to vulnerability. Another approach is to examine trends in factors that increase or decrease vulnerability. These are generally factors of everyday life such as those set out in the paragraph above.

Higher levels of vulnerability may evolve from the sequence of natural and technological events and the interactions between them. For example, the initial disaster agent may be an invisible contaminant which affects the mental and physical health of those involved, with impacts persisting for years. Such impacts may undermine local resilience for subsequence events. A different sequence of events is that of a drought helping to create conditions ideal for wildfire, a high intensity wildfire resulting in ecological damage then exacerbated by a continuing drought that inhibits ecological and livelihood recovery, or heavy rain on the soil made bare by fire with serious erosion and similar losses.

4.3.4.2. Global and Regional Trends in Vulnerability Factors

Overall vulnerability appears to be fairly stable, although this general statement conceals a diverse range of trends including areas and groups where the trends are negative.

Dispossession by war or civil strife

Refugees and those driven into areas where livelihoods are marginal are often the most dramatic examples of people vulnerable to the negative affects of natural events, cut off from coping mechanisms and support networks. About half the world's countries are directly linked to uprooted populations with people being forced to flee in some sixty countries (US Committee for Refugees 2000). Where warfare is involved, these areas are also characterized by an exodus of trained people and an absence of inward investment. Reasons for the increase in vulnerability associated with warfare include destruction or abandonment of infrastructure (transport, communications, health, education) and shelter, redirection of resources from social to military purposes, collapse of trade and commerce, abandonment of subsistence farmlands, lawlessness and disruption of social networks (Levy and Sidel 2000).

Poverty

The impacts of disaster are greatest on poorest households. Prevention's *Global risk assessment* (2009) found that "Poor households are usually ..less resilient to loss and are rarely covered by insurance or social protection. Disaster impacts lead to income and consumption shortfalls and negatively affect welfare and human development, often over the long term." Disaster impacts produce other poverty outcomes as well. Evidence from the 1984 drought and famine in Ethiopia shows that school enrolment tends to fall and children may grow at a slower rate due to nutritional shortfalls following disasters (Prevention, 2009). If people do not have enough to eat in normal times, they will be particularly badly impacted by extreme climatic events.

At the global level, it appears that poverty is decreasing. An important exception are the poorest billion people for whom income increased only slightly over the last decade. For the poorest ten percent the situation is much worse with a decrease in income (Nielsen, 2009). The number of those going hungry is increasing at about 4 million a year (FAO – SOFI, 2009) with a total of about 820 million. Over the last decade the proportion of people suffering from hunger in developing countries has gone down very slightly from 20 to 17 percent (FAO – SOFI, 2009).

Urban poor and informal settlements (from Prevention 2009)

Approximately one billion people worldwide live in informal settlements and the numbers are growing by approximately 25 million per year. Poor people in informal urban settlements typically have higher levels of everyday risk, even without considering the impact of natural hazards. For example, in Nairobi under-five mortality rates were 61.5 per 1,000 live births for the city as a whole in 2002, but approximately 150 per 1,000 in informal settlements. Evidence from cities in Africa, Asia and Latin America, shows that the expansion of informal settlements is closely associated with the rapid increase in weather-related disaster reports in urban areas. The comments on poverty and vulnerability above apply here as well.

Small island countries (from Prevention 2009)
"Countries with small and vulnerable economies, such as many small-island developing states ..(SIDS) and land-locked developing countries (LLDCs), have the highest economic vulnerability to natural hazards. Many also have extreme trade limitations."

Emergency support (from Prevention 2009)
"In general terms, countries are making ..significant progress in strengthening capacities, institutional systems and legislation to address deficiencies in disaster preparedness and response. Good progress is also being made in other areas, such as the enhancement of early warning. In contrast, countries report little progress in mainstreaming disaster risk reduction considerations into social, economic, urban, environmental and infrastructural planning and development."

Ecosystems
The Millennium Assessment found that the supply of approximately 60% of the ecosystem services evaluated (15 of 24) was in decline. However, consumption of almost all ecosystem services is increasing. Demand and service flow is increasing as the stock is decreasing. People have modified ecosystems to increase the supply of provisioning services, these same modifications have led to the decline of regulating ecosystem services, including those responsible for mitigating hazards, such as fires and floods (Millennium Ecosystem Assessment 2005).

4.3.4.3. Observed Trends in Human Systems and Sector Vulnerability to all Climatic Extremes and to Specific Types of Hazards

Water sector
The "water sector" includes:

- Provision of water supplies to customers (municipal, industrial, agricultural)
- Management of the flood hazard (coastal, river and pluvial)
- Management of water quality (for environmental and public health reasons)
- Management of freshwater ecosystems.

Changes in vulnerability to climate extremes in the water sector are driven by both changes in the volume, timing and quality of water (Section 4.3.3) and changes in the property, lives and systems using the water resource or exposed to water-related hazard. With a constant resource or physical hazard, there are two opposing drivers of change in vulnerability. On the one hand, vulnerability increases as more demands are placed on the resource (due to increased water consumption, for example, or increased discharge of polluting effluent) or more property, assets and lives are exposed to flooding. (*There are many published examples of trends on flood losses / water resource scarcity / pollutant loadings – perhaps tabulate some?*). On the other hand, vulnerability is reduced as measures are implemented to improve the management of resources and hazards, and to enhance the ability to recover from extreme events. For example, enhancing water supplies, improving effluent treatment and improved flood management measures (including the provision of insurance or disaster relief) would all lead to reductions in vulnerability in the water sector. The change in vulnerability in any place is a function of the relationship between these two opposing drivers, which also interact. Flood or water management measures may reduce vulnerability in the short term, but increased security may generate more development and ultimately lead to increased vulnerability.

The number of water-related disaster has increased at global scale for recent years (see Figure 4-8). The factors that have led to increased water-related disasters are thought to include natural pressures, such as climate variability; management pressures, such as the lack of appropriate organizational systems and inappropriate land management; and social pressures, such as an escalation of population and settlements in high-risk areas (particularly for poor people) (Adikari and Yoshitani, 2009). Contribution of factors to the increasing trend in water-related disasters is site-specific and cannot be concluded without detailed analysis. However, through the analysis of historical time-series data of disaster, trend in vulnerability to water-related hazards can be roughly understood.

[INSERT FIGURE 4-8 HERE:
Figure 4-8: Water-related disaster events recorded globally, 1980 to 2006 (Adikari and Yoshitani, 2009).]

Adikari and Yoshitani (2009) analyzed trends in water-related disasters based on CRED data for the period 1980 to 2006. Table 4-9 summarizes the recent trend of water-related disasters by hazard. Water-related disasters are clearly increasing every year and that future development is just as much at risk. However, the number of fatalities has decreased drastically, due to the efforts of those involved in the process of disaster management. As typical successful practice, we can exemplify the experience of Bangladesh where the numbers of fatalities due to similar magnitude cyclones decreased from more than 300000 in 1970 to just over 5000 people in 2007 (Adikari and Yoshitani, 2009), and the experience of Mozambique whose death tolls of serious floods in 2007 and 2008 were much smaller than that in 2000 (International Federation of Red Cross and Red Crescent Societies, 2009). Both cases can be linked to the progress in disaster management including effective early warning system. However, these good cases do not mean that early warning systems have evolved sufficiently to avoid massive casualties from natural hazards, as demonstrated by the 138,000 deaths in 2008 from Cyclone Nargis in Myanmar (International Federation of Red Cross and Red Crescent Societies, 2009).

[INSERT TABLE 4-9 HERE:
Table 4-9: Trend of water-related disasters from 1980 to 2006 by hazards (based on Adikari and Yoshitani, 2009).]

For thinking about historical change in vulnerability to droughts, it would be worth capturing trends of water withdrawal, demand side. With rapid population growth water withdrawals have tripled over the last 50 years. This trend is explained largely by the rapid increase in irrigation development stimulated by food demand in the 1970s and by the continued growth of agriculture-based economies. Emerging market economies (such as China, India and Turkey) still have an important rural population dependent on water supply for food production. They are also experiencing rapid growth in domestic and industrial demands linked to urbanization and related changes in lifestyle. There are hot spots in these countries where rural and urban demands are in competition (World Water Assessment Programme,2009).

Economy and transport

There is increasing vulnerability to weather/climate extremes partly because of the increasing value of assets exposed, but partly also because of increased interconnections between systems/sectors/places. The normal practice of just in time management and logistics is efficient financially but results in very little capacity in the event of a system breakdown as a result of an extreme event for example. Increasing volumes of traffic of all types increasingly takes systems to full capacity resulting in severe disruption to dependent sectors from for example a extreme weather event. Extreme events in one place can therefore have knock-on effects to other parts of the economy in other places.

Human Health

The largest research gap is a lack of information on impact outcomes in developing countries in general. This includes mortality/morbidity data and information on other contributing factors such as nutritional status or access to safe water and medical facilities. Only a limited number of places in developing countries have been investigated. The lack of information is inherent in developing countries, where public health infrastructure is poor and where the impact would be greatest due to both severe hazards and lower coping capacity. Within the developing countries, lower socio-economic status usually worsens vulnerability.

4.3.4.4. Case Study – Extraordinary Heat Wave in Europe, Summer 2003

An extraordinarily severe heat wave over large parts of the European continent occurred in the summer of 2003. It produced record-breaking temperatures particularly during June and August (Beniston, 2004; Schär *et al*., 2004). Absolute maximum temperatures exceeded the record highest temperatures observed in the 1940s and early 1950s in many locations in France, Germany, Switzerland, Spain, Italy and the UK. In many places of southern Europe, the peak temperatures exceeded 40°C.

Average summer (June to August) temperatures were by up to five standard deviations above the long-term mean, implying that this was an extremely unlikely event under current climatic conditions (Schär and Jendritzky, 2004). Gridded instrumental temperatures (from CRUTEM2v for the region 35°N–50°N, 0–20°E) show that the summer was the hottest since comparable records began in 1780: 3.8°C above the 1961 to 1990 average and 1.4°C hotter than any other summer in this period. Based on early documentary records, Luterbacher *et al.* (2004) estimated that 2003 is very likely to have been the hottest summer since at least 1500. As such, the 2003 heat wave resembles simulations by regional climate models of summer temperatures in the latter part of the 21st century under the A2 scenario (Beniston, 2004). Anthropogenic warming may therefore already have increased the risk of heatwaves such as the one experienced in 2003 (Stott *et al.*, 2004).

The heat wave od the summer of 2003 was accompanied by annual precipitation deficits in many parts of western and central Europe, up to 300 mm (Trenberth *et al.*, 2007). This led to considerable reduction of soil moisture and surface evaporation and evapotranspiration, and thus to a strong positive feedback effect (Beniston and Diaz, 2004). The drought contributed to the estimated 30% reduction in gross primary production of terrestrial ecosystems over Europe (Ciais *et al.*, 2005). This reduced agricultural production and increased production costs. The (uninsured) economic losses for the agriculture sector in the European Union were estimated at €13 billion, with largest losses in France (€4 billion) (Sénat, 2004). A record drop in crop yield of 36% occurred in Italy for maize grown in the Po valley, where extremely high temperatures prevailed (Ciais *et al.*, 2005). In France, compared to 2002, the maize grain crop was reduced by 30% and fruit harvests declined by 25%. The hot and dry conditions led to many very large wildfires. The extreme glacier melt in the Alps prevented even lower river flows in the Danube and Rhine (Fink *et al.*, 2004).

The 2003 heatwave *cum* drought in Europe affected settlements and economic services in a variety of ways, creating stress on health, water supplies, food storage and energy systems. Many major rivers (e.g., the Po, Rhine, Loire and Danube) were at record low levels, resulting in disruption of inland navigation, irrigation and power-plant cooling (Beniston and Díaz, 2004; Zebisch *et al.*, 2005). In France, electricity became scarce, construction productivity fell, and the cold storage systems of 25-30% of all food-related establishments were found to be inadequate (Létard *et al.*, 2004). The punctuality of the French railways fell to 77%, from 87% twelve months previously. Sales of clothing were 8.9% lower than usual in August, but sales of bottled water increased by 18%, and of ice cream by 14%. The tourist industry in Northern France benefited, but in the South it suffered (Létard *et al.*, 2004).

Impacts of the heatwave were mainly health- and health-service related; but they were also associated with settlement and social conditions, from inadequate climate conditioning in buildings to the fact that many of the dead were elderly people, left alone while their families were on vacation. Electricity demand increased with the high heat levels; but electricity production was undermined by the facts that the temperature of rivers rose, reducing the cooling efficiency of thermal power plants (conventional and nuclear) and that flows of rivers were diminished; six power plants were shut down completely (Létard *et al.*, 2004).

The excess deaths due to the extreme high temperatures during the period June to August, in Belgium, the Czech Republic, Germany, Italy, Portugal, Spain, Switzerland, the Netherlands and the UK, may amount to 35,000 (Kosatsky, 2005). Elderly people were among those most affected (WHO, 2003; Kovats and Ebi, 2006) – in France, around 60% of the heat wave deaths occurred in persons aged 75 and over (Hemon and Jougla, 2004). The heat wave in 2003 has led to the development of heat health-watch warning systems in several European countries – many governments (local and national) have implemented heat health-prevention plans , most of which are targeted towards a reduction of the short-term mortality (Michelozzi *et al.*, 2005; WHO Regional Office for Europe, 2006; Pascal, 2008).

In July 2006, France experienced the first major heat wave since the implementation of its heat prevention plan. Following the hypothesis that heat-related mortality had not changed since 2003, 6452 excess deaths were predicted from the observed temperatures, i.e. substantially less than observed 2065 excess deaths that actually occurred. The mortality lower than expected can be partially explained by a decrease in the population’s vulnerability and by the efficiency of the prevention plan (Pascal, 2008).

4.3.4.5. Case Study – Glacial Retreat: Himalaya and Andes [move to Chapter 3?]

Glaciers in temperate and tropical latitudes are considered one of the best indicators of climate change, due to their sensitivity to climatic variations and public perception of temperature change in mountain regions (IPCC in McCarthy *et al.*, 2001; Haeberli, 2006). In general terms, valley glacier fluctuations have followed a similar pattern to temperature change, with strong glacier retreats in the 1940s, stable or growing conditions around the 1970s, and again increasing rates of ice loss since the mid 1980s (WGMS, 2008; see Figure 4-9). Small glaciers have retreated at faster rates than large glaciers due to a lag time in response of the latter; similarly, low latitude and/or low elevation mountain glaciers shrink faster than high latitude and/or high elevation glaciers (WGMS, 2008). In the Himalayas, the average rate of glacier retreat is ca 10 m per year, although in extreme cases, such as Imja glacier, it has increased from 59 m per year (1962-2001) to 74 m over the period 2001-2006 (Bajracharya, 2007). A direct effect of glacier dynamic is the formation and disappearance of ice- and moraine-dammed lakes. Moraine-dams may experience degradation through melting of ice cores (Richardson and Reynolds, 2000), erosion and seepage (O'Connor *et al.*, 2001), and their glacial lakes may increase in volume from accelerated glacier melting (Clague and Evans, 2000). Existing glacier-dammed lakes may also drain catastrophically through ice-marginal drainage, mechanical failure of part of the ice dam or by a tunnel incised into the basal ice or a combination of both (Walder and Costa, 1996).

[INSERT FIGURE 4-9 HERE:
Figure 4-9: Anomalies in northern hemisphere snow cover since 1965 (UNEP GRID, ____).]

Glacial outburst floods are highly threatening because they occur suddenly with little or no warning, and therefore floods are unexpected for riverine communities, and can be much larger than usual rain or snowmelt floods. Common flood discharges from historically breached moraine dams range between 200-4000 m^3s^{-1}, but at least on two outburst floods a peak was recorded of 10,000 m^3s^{-1} for a drained volume in excess of 18 million m^3 of water (e.g. Tam Pokhari Glacier Lake in Nepal after a 60 m-height dam collapse, Dwivedi *et al.*, 2000). Ice-dammed lake failures have produced a larger peak discharge than moraine lakes containing similar water volume, with the largest one reaching 112,500 m^3s^{-1} (October 1986 GLOF from Russell Fjord; Mayo, 1989), about three times the largest Mississippi flood. Outburst from small subglacial, supraglacial and englacial water bodies also may cause flood hazards for down valley human activities.

Areas susceptible to outburst floods are inherent to the presence of large proglacial lakes including the Himalayas (Yamada, 1998; Mool *et al.*, 2001; Richardson and Reynolds, 2000), the Andes (Ames *et al.*, 1989; Kaser and Osmaston, 2002; Dussaillant *et al.*, 2009), the Alps (Lliboutry *et al.*, 1977, Haeberli *et al.*, 2001; Huggel *et al.*, 2004; Kaab *et al.*, 2005), central Caucasus (Petrakov *et al.*, 2007), and the Cordillera of western North America (Clague and Evans, 2000; O'Connor *et al.*, 2001). An inventory of glacial lakes in Himalayas shows a potential high risks on 24 of 2,674 glacial lakes in Bhutan, 20 of 2,323 glacial lakes in Nepal, 16 of 156 glacial lakes in India (data from three states: Himachal Pradesh, Uttarakhand and Sikkim), and 52 of 2,420 glacial lakes in Pakistan (ICIMOD in Bajracharya *et al.*, 2007). During the 1934-1998 period, the frequency of glacial-lake outburst floods in the Himalayas of Nepal, Bhutan and Tibet has increased from 0.38 events/year in 1950s to 0.54 events/year in 1990s (Richardson and Reynolds, 2000 in Rosenzweig *et al.*, 2007). In the Andes region, although still largely unknown, vulnerable sites amount to over a dozen glacial and moraine lakes in Chile (Peña and Escobar, 1983; Harrison *et al.*, 2006), and in Cordillera Blanca (Peru) as ca 600 glaciers have retreated ~25% over the last 30 years, with an increase on number of glacial lakes from 223 in 1953 to 374 in 1997, among which precarious dam conditions were identified in at least 35 glacial lakes (Carey, 2005). In the Northern Patagonia Ice Field, the rapid succession of five outburst floods from ice-dammed lake Cachet 2 (230 million m^3) during 2008-2009 caused considerable damage to local settlements along the Baker River, after more than 40 years without any outburst flood event (Dussaillant *et al.*, 2009).

Glacier retreat is increasing the number and size of glacial lakes, requiring an extra effort for inventory and monitoring of existing and new developed lakes. The highest GLOF hazard is usually related to glacial lakes dammed by young, unstable and unconsolidated moraines, and lakes in contact to the active ice body of a glacier (Damen, 1992). Processes involved in the formation and disappearance of glacial lakes are very dynamic in the current warming conditions (Quincey *et al*., 2007), and new emerging lakes may cause a catastrophic disaster in areas not considered to be GLOF-prone, and vice-versa (Osti and Egashira, 2009). In fact, it is not unusual that local population learn about the very existence of a glacial lake after it has produced a GLOF event (Petrakov *et al*., 2007). Remote sensing techniques, namely SAR interferometry, LIDAR and satellite images (Landsat, Spot and IRS), are being used to identify and monitor glacial lake changes (Huggel *et al*., 2004; WGMS, 2008), and as a predictive tool for identifying those glaciers with an expected tendency towards lake formation over a time-scale of the order of a few decades (Quincey *et al*., 207). The most unstable glacial lakes require real time monitoring of both lake and glacier, together with updated hazard maps and mitigation measures, mainly at the source, via lake monitoring and controlled drainage (Grabs and Hanish, 1993). Other elements requiring monitoring include dam failure triggering events (e.g. large ice mass from glacier tongue resulting in surge waves and lake overflow), and dam stability (e.g. seepage and piping resulting in local dam failure: Grabs and Hanish, 1993; Haeberli *et al*., 2001), and seismic activity, particularly on those areas with active volcanism (e.g. Iceland *et al*., 2003).

Human activities affected by glacial hazards include settlements, hydropower production, forestry, mining and wilderness tourism (Clague and Evans, 2000; Richardson and Reynolds, 2000). Rapid socio-economic growth of mountain regions increases the GLOF risk potential, and actions are needed to identify and monitor hazard sources, identify downstream vulnerable zones, reduce and mitigate GLOF risk, prevent life losses and minimize economic losses (Table 4-10). New economic activities introduced on mountain regions, such as hydropower plant developments, may underestimate GLOF risks. A small hydropower plant in Nepal was destroyed by an outburst flood from the Dig Tsho Lake, in August 1985 (Vuichard and Zimmermann, 1987). This is particularly relevant in view of the planned development of large hydropower projects in the Baker River in Chilean Patagonia, now questioned after the five self-forming outburst floods from Cachet 2 Lake (Dussaillant *et al*., 2009). Effective risk management should address the changing vulnerability and new patterns of glacial-related hazards with severe socio-economic consequences (Rosenzweig *et al*., 2007). Adaptation measures are limited and in most cases requires a relocation of human settlements and new risk assessment for planned infrastructure (hydropower, bridges, etc.) in the view of potential outburst floods (Adger *et al*., 2007).

[INSERT TABLE 4-10 HERE:
Table 4-10: Risk, glacier outburst floods, and management.]

4.3.5. Observed Trends in Ecosystem Vulnerability to all Climatic Extremes and to Specific Types of Hazards (e.g., drier, hotter, conditions can lead to very high intensity fires)

Extreme climatic events have increased in frequency and magnitude, but their ecological impacts are far away from fully understood. Climatic extremes (drought, heat wave, flood, frost, ice, and storm) and specific hazards were observed to have widespread effects on ecosystems, including physiology, development, biodiversity, phenology and carbon balance.

4.3.5.1. Drought and Heat Wave

The effects of drought and heat wave were widespread. A higher sensitivity to drought was found in the beech, and surprisingly, in the broadleaved Mediterranean forests; the coniferous stands (spruce and pine) appeared to be less drought-sensitive (Granier, Reichstein et al. 2007). The effects of drought accompanied by extreme warm temperature mainly include growth decline, species death or mortality, spatial shift and carbon balance.

4.3.5.1.1. Growth decline

The aboveground net primary productivity declined at a short grass steppe site in Colorado, USA at the two years of extreme drought (1954 and 1964) (Lauenroth *et al*., 1992). A crown condition declined following severe droughts for beech such as drought in 1976 (Power, 1994), 1989 (Innes, 1992) and 1990 (Stribley *et al*., 2002)). The percentage of moderately or severely damaged trees displayed an upward trend after the 1989's drought in Central

Italy, especially for *Pinus pinea* and *F. sylvatica* (Bussotti *et al*., 1995). Defoliation and mortality in Scots pine observed in each year during 1996–2002 was related to the precipitation deficit and hot conditions of the previous year in the largest inner-alpine valley of Switzerland (Valais) (Rebetez *et al*., 2004). Both gross primary production and total ecosystem respiration decreased in 2003 in many regions of Europe (Granier, Reichstein et al. 2007).

The time-lag between climatic extremes and forest decline is widespread, which may enhance vulnerability to more frequent climate extremes. Five years after the exceptional 2003 summer, forest declines are mentioned in many forests all over Europe. The unusual heat and drought in summer 2003 caused a severe reduction in water availability and transpiration of several forests stands in Central Europe. This led to leaf loss increase on these plots for many species as soon as 2004 and the following years (Bréda *et al*., 2008). The growth reduction in beech was more pronounced in the year following the drought (2004) (Granier, Reichstein et al. 2007). Although precipitation recovered to near normal levels in the ensuing years after extreme drought, the aboveground net primary productivity showed a lag in recovery of 1–3 years, which they attribute to changes in vegetative structure (Lauenroth *et al*., 1992).

4.3.5.1.2. Species death or mortality

The death of species was the ultimate stage triggered by extreme drought that acts as a bottleneck event affecting changes in co-occurring species. Abnormal mortality was observed either soon after the climatic event (autumn 2003), or at the beginning of 2004 when spring budburst did not arise for a lot of trees. A mortality rate of 1.3% for coniferous trees was observed in French, representing a spectacular increase in comparison with the average normal level of 0.2%. At the European scale, tree mortality varied from 0.8 to 1.2%, with a continuous increase up to 2006 after recurrent droughts, especially for broad-leaved species. The exceptional increase of coniferous species mortality in 2004 was the result of earlier, stronger and longer soil water deficit, direct impact of heat wave on crowns (Bréda *et al*., 2008).

A rapid, drought-induced die-off of overstory woody plants at sub-continental scale was triggered by the recent drought (2000-2003) in southwestern North America. After 15 months of depleted soil water content, >90% of the dominant, overstory tree species (*Pinus edulis*, a piñon) died. The limited, available observations suggest that die-off from the recent drought was more extensive than that from the previous drought of the 1950s, extending into wetter sites within the tree species' distribution (Breshears *et al*., 2005). Regional-scale pinon pine mortality was following an extended drought (2000–2004) in northern New Mexico (Rich *et al*., 2008). Dominant species from diverse habitat types (i.e., riparian, chaparral, and low-to-high-elevation forests) exhibited significant mortality during a drought in the southwestern United States; and average mortality differed among dominant species was 3.3%-41.4% (Gitlin *et al*., 2006).

4.3.5.1.3. Spatial shift

A rapid shift of a forest ecotone was caused by *Pinus ponderosa* mortality in response to the 1950s drought (Allen et al., 2005). The severe drought in 2004–2005 was responsible for spatial shifts in the estuary regarding zooplankton community and inter-annual variability, with an increase in abundance and diversity during the period of low freshwater flow in a shallow temperate southern European estuary, the Mondego Estuary Portugal. The occurrence of such estuarine community contributed to the increase in zooplankton abundance which is ascribed to the estuarine species *Acartia tonsa*. (Marques *et al*., 2007).

4.3.5.1.4. Carbon balance

More frequent anomalously warm years may lead to a sustained decrease in carbon dioxide uptake by terrestrial ecosystems. The extreme conditions pushed many forest ecosystems from being a net C sink to being a net C source. Net ecosystem carbon dioxide exchange decreased in both the extreme warming year (2003) and the following year in tall-grass prairie in central Oklahoma, USA (Arnone *et al*., 2008). A 30% reduction in gross primary productivity together with decreased ecosystem respiration over Europe during the heatwave in 2003, which resulted in a strong anomalous net source of carbon dioxide (0.5 Pg Cyr(-1)) to the atmosphere and reversed the effect of four years of net ecosystem carbon sequestration. Such a reduction in Europe's primary productivity is unprecedented during the last century (Ciais *et al.*, 2005). As for grassland ecosystems, the significant decrease in the efflux of CO_2, which was equal to about 1/5 of that during the corresponding period of 1998, resulted from extreme drought in Inner Mongolia, China in 2001 (Li *et al.*, 2004).

4.3.5.2. Flood

An extreme flood event was punctuational perturbations that caused large, rapid population- and community-level changes that were superimposed on a background of more gradual trends driven by climate and vegetation change (Thibault *et al.*, 2008).

An extreme flood event affected a desert rodent community near Portal, AZ since 1977 by causing catastrophic, species-specific mortality and resulting in rapid, wholesale reorganization of the community (Thibault *et al.*, 2008). Floods were observed to directly impact on Huelva, by wiping out part of its population in the Mondego estuary, located on the Atlantic coast of Portugal. Over the period when the estuary experienced eutrophication, extreme weather events contributed to the overall degradation of the estuary, while during the recovery phase following the introduction of a management programme, those extreme weather episodes delayed the recovery process significantly (Cardoso *et al.*, 2008).

4.3.5.3. Storm

Winter storms are considered key climate risks, particularly in prealpine and alpine areas (Fuhrer *et al.*, 2006). Since 1868 European forests were impacted at least 16 times by the effects of several severe storms (Schelhaas *et al.*, 2003), and 10 times since the early 1950s with windthrow of over 20 million m3; damages in 1990 and 1999 were by far the worst of all these years (UN/ECE Timber Committee, 2000). A damaging ice storm struck northern New England, NY, and adjacent Canada in 1998, affecting nearly 7 million ha of forest lands (Faccio, 2003).

4.3.5.4. ENSO

The El Niño-Southern Oscillation (ENSO) events have strong ecological consequences, especially changes in marine ecosystems. Particularly striking were widespread massive coral bleaching events that followed the 1982-1983 (Glynn, 1988) and 1997-1998 (Wilkinson, 1999) El Niño events. There has been significant bleaching of hard and soft corals in widely separate parts of the world from mid-1997 to the last months of 1998. Much of this bleaching coincided with a large El Nino event, immediately switching over to a strong La Nina. Some of the reports by experienced observers are of unprecedented bleaching in places as widespread as (from west to east) the Middle East, East Africa, the Indian Ocean, South, Southeast and East Asia, far West and far East Pacific, the Caribbean and Atlantic Ocean. Catastrophic bleaching with massive mortality was reported, often near 95% of shallow (and sometimes deep water) corals such as in Bahrain, Maldives, Sri Lanka, Singapore, and parts of Tanzania (Wilkinson, 1999).

By contrast, the effects of ENSO events on terrestrial ecosystems have been seldom investigated. ENSO-induced pulses of enhanced plant productivity can induce the spectacular greening and flowering of deserts (Dillon *et al.*, 1990), and can cause open dry-land ecosystems to shift to permanent woodlands (Holmgren *et al.*, 2001).

No information does not means that no problems of adverse impacts of extreme events and disasters on ecosystems in developing societies. (Because of lack of researches or maybe lack of only references in English, there are fewer literatures on climate extreme impacts of climate change and disasters on ecosystems. It is likely that the researches in developing countries were published in other languages than English. For example, the on-going second National

Assessment Report on Climate Change in China would include such information of China. The report have not yet been allowed to cite or reference)

4.3.5.5. Case Study – Coral Reef Bleaching

Coral reefs are common features in tropical and subtropical coasts, providing ecosystem service that includes food production, tourism and recreation, and disturbance regulation (coastal protection). The economic value of the world's coral reefs was estimated to be 29,830 million US$ and 797,530 million US$ for net benefit per year and net present value over a 50-year timeframe, respectively (Cesar, 2003). Coral reefs, however, suffer rapid degradation (Hoegh-Guldberg *et al.*, 2007). Recent estimate shows that 20% have been destroyed, and 50% are threatened (Wilkinson, 2004). One-third of coral species face elevated extinction risk (Carpenter *et al.*, 2008).

One of the major causes is coral reef bleaching, due to the loss of symbiotic algae, which has most commonly been associated with anomalously high sea surface temperatures (SSTs), typically with 1.0-1.5 ˚C above seasonal maximum mean SSTs (e.g., Baker *et al.*, 2008). The number of bleaching events observed is increasing (see Figure 4-10), possibly in response to SST rise due to global warming. Retrospective analysis of SSTs and bleaching occurrences indicated that bleaching was correlated well with anomalously high SST (e.g., Berkelmans *et al.*, 2004; McWilliams *et al.*, 2005).

[INSERT FIGURE 4-10 HERE:
Figure 4-10: Coral bleaching record.]

Of all the years, the 1998 bleaching was unprecedented and most devastating in its geographical extent and severity. It was caused by anomalously high SST because of pronounced El Nino events in one of the hottest year on record (Lough, 2000). This event caused mass mortality of corals and damaged coral reefs' ecosystem service not only in food production and tourism and recreation but also in disturbance regulation. For example, in Seychelles of the Indian Ocean, the function of coastal protection due to coral reefs was partially lost due to coral mortality (Sheppard *et al.*, 2005). Overall, the total economic damage estimated over a 20-year timeframe was calculated to be maximum 8,190 million US$ for the Indian Ocean (Wilkinson *et al.*, 1999).

The rising SST could cause higher bleaching intensity in the future. Results from atmosphere-ocean general circulation models (GCMs) from the third assessment of IPCC indicated that bleaching could become an annual or biannual event for the vast majority of the world's coral reefs in the next 30-50 years (Donner *et al.*, 2005). Using more recent GCMs, Donner *et al.* (2007) and Yara *et al.* (2009) showed similar trends in the eastern Caribbean and northwestern Pacific, respectively. As evidenced in 1998, pronounced El Nino events caused by climate change would make bleaching more severe.

Though anomalously high SSTs have been accepted as the major cause of widespread bleaching, refining the prediction and consequences may be required, because bleaching and the resulting coral mortality can be a result of interaction of various environmental variables (including SST) and acclimatization of corals. Bleaching could be caused by other stressors, including ocean acidification (Anthony *et al.*, 2008), high solar radiation, freshwater discharge and sedimentation, all of which are related to climate change and human activities. On the other hand, bleaching may be mitigated by strong water motion (Nakamura *et al.*, 2005), sometimes caused by typhoons (Manzello *et al.*, 2007), which are also related to climate change. Further, adaptation and acclimatization of corals to high SST could happen (Baker *et al.*, 2008). These recent advances in knowledge of coral bleaching may require considering multiple variables to estimate susceptibility of current and future coral reefs (e.g., Donner *et al.*, 2005, 2007; McClanahan *et al.*, 2007; Maina *et al.*, 2008).

4.3.6. Issues of Sequencing and Frequency of Climatic Extremes (e.g., ratcheting effect) [on impacts]. The impact of multiple hazards each one of which is not necessarily an "extreme".

[*Placeholder Only*] The sequence or order of climatic extremes can have a major affect in a number of ways. The sequence can undermine resilience where an event makes people or ecosystems more vulnerable or more exposed to another extreme. This can happen through damage to livelihoods or to areas that protect settlements or otherwise vulnerable ecosystems. Sequences need not necessarily all be "extreme events". Frequent relatively small events can alter ecosystems and impair livelihoods in ways that are not noticed by external observers.

4.3.7. Comment on 4°C Rise

To be completed.

4.4. System- and Sector-Based Aspects of Vulnerability, Exposures, and Impacts

4.4.1. Criteria Used for the Tables in this Section

The information is set out in Table 4-11. This table considers systems and sectors by exposure, vulnerability and impacts. Systems are human and natural (ecosystems). Sectors considered are: food, health, water, ecosystem, forestry, tourism, economy, infrastructure/settlements, energy and other. Exposure and vulnerability are as defined earlier in this chapter with vulnerability being susceptibility to harm and capacity to recover. Exposure is being in the way of the climatic extreme. All climatic extremes covered in Chapter 3 plus wildfires and erosion.

[INSERT TABLE 4-11 HERE:
Table 4-11: Links between sectors, exposure, vulnerability, and impacts.]

Data on impacts are generally available at various levels of aggregation. But these often do not allow the issues of the severity of the natural phenomenon, exposure and vulnerability to be examined separately. Without either this capacity or careful normalization of the data to isolate the factors we are interested in, the results do not tell us much about the issues we want to examine.

4.4.2. The Overall Links between Systems, Sectors, and Hazard Impacts (including vulnerability and exposure)

In this sub-section, according to the criteria discussed in 4.1, existing studies which assessed impacts and risks of extreme events or extreme impacts are surveyed for each major affected sectors/system. Generally, there is limited literature on the potential future impacts of extreme events, while most literature is subject to work on analyzing current risks of extreme events based on observed states and trends of factors. It might be partially due to the limited availability of reliable detailed knowledge on change in extreme events as well as other various factors related to vulnerabilities in future. However, if factors constituting current risks are understood and sorted out, stakeholders including policymakers could make use of the knowledge for thinking of future risks roughly and preparing for them with various kinds of policy and measures. Therefore analyses of observed impacts due to extreme events as well as of projected future risks are taken up. Below, coverage of knowledge on current/future risks of extreme events is evaluated and findings of major researches are introduced by sectors/systems.

4.4.2.1. Water

This section assesses evidence for future changes in extreme aspects of freshwater resources, focusing on water supply and floods (coastal floods are covered in Section 4.4.2.4). The evidence is assessed at the "local" scale (the scale at which water supplies and floods are managed), the national scale and the international scale.

In terms of water supply, an extreme event is one which challenges the ability of the water supply "system" (from highly-managed systems with multiple sources to a single rural well) to supply water to users. This may be because a surplus of water affects the operation of systems, but more typically results from a shortage of water relative to demands – a drought. Water supply shortages may be triggered by a shortage of river flows and groundwater, a deterioration in water quality, an increase in demand, or an increase in vulnerability to water shortage. Reductions in river flows or groundwater recharge may be a result of climate change (see Chapter 3), of changes in catchment land cover, or changes in upstream interventions. A deterioration in water quality may be driven by climate change (Chapter 3), change in land cover or upstream human interventions. An increase in demand may be driven by demographic, economic, technological or cultural drivers (Chapter 2). An increase in vulnerability to water shortage may be caused by, for example, increasing reliance on specific sources or volumes of supply, or changes in the availability of alternatives (Chapter 2). Indicators of hydrological and water resources drought impact include lost production (of irrigated crops, industrial products and energy), the cost of alternative or replacement water sources, and altered human well-being, alongside consequences for freshwater ecosystems (impacts of meteorological and agricultural droughts on production of rain-fed crops are summarised in Section 4.4.2.3).

Although there have been many studies simulating potential effects of climate change on various hydrological indicators of drought at the local scale (see Chapter 3), very few studies have so far been published into the effect of climate change on the impacts of drought. Virtually all of these have looked at water system supply reliability during a drought, rather than indicators such as lost production, cost or well-being. Changes in reliability of course vary with local hydrological and water management circumstances, the details of the climate scenarios used, and the influence of changes in other drivers on drought risk. Some studies show large potential reductions in supply reliability due to climate change that challenge existing water management systems (e.g. Fowler et al., 2003, Vanham et al., 2009), some show relatively small reductions that can be managed – albeit at increased cost – by existing systems (e.g. Fowler et al., 2007), and some show that under some scenarios the reliability of supply *increases* (e.g. Kim and Kalvarachi, 2009; Li et al. 2010). Climate change is in many instances only one of the drivers of change in supply reliability, and is not necessarily the most important local driver. Macdonald et al. (2009), for example, demonstrate that the future reliability of small-scale rural water sources in Africa is largely determined by local demands, biological aspects of water quality or access constraints, rather than changes in regional recharge - because domestic supply requires only 3-10 mm of recharge per year. However, they noted that up to 90 million people in low rainfall areas (200-500mm) would be at risk if rainfall reduces to the point at which groundwater resources become non-renewable.

A number of countries have published national-scale assessments of the consequences of climate change and other drivers on the impacts of hydrological or water resources drought (e.g. Spain: Iglesias et al., 2005). There have been several continental or global scale assessments of potential change in hydrometeorological drought indicators (see Chapter 3), but only one published study of potential changes in an indicator of water resources drought *impact*. Lehner et al. (2006) calculated a drought deficit volume indicator across Europe, based on simulated river flows with consumptive abstractions (for municipal, industrial and agricultural uses) removed. They showed very substantial changes in the future return period of the present 100-year water resources drought deficit volume (see Figure 4-11a) with two climate scenarios: across large parts of Europe, the present 100-year drought deficit volume would have a return period of less than 10 years by the 2070s. Lehner et al. (2006) also demonstrated that this pattern of change was generally driven by changes in climate, rather than the projected changes in withdrawals of water (see Figure 4-11b). In southern and western Europe, changing withdrawals alone only increases deficit volumes by less than 5%, whereas the combine effect of changing withdrawals and climate change increases deficit volumes by at least 10%, and frequently over 25%. In eastern Europe, increasing withdrawals increase drought deficit volumes by over 5%, and more than 10% across large areas, but this is offset under both climate scenarios by increasing runoff.

[INSERT FIGURE 4-11 HERE:
Figure 4-11: Change in indicators of water resources drought across Europe by the 2070s (Lehner et al., 2006). a (top): change in the return period of the current 100-year drought deficit volume, with change in river flows and withdrawals, under two climate scenarios. b (bottom): change in the intensity (deficit volume) of the 100-year drought with changing withdrawals, with climate change (left, with the HadCM3 scenario) and without climate change (right).]

In terms of fluvial (river-based) floods, an extreme event is one which causes loss, damage or inconvenience to those living or working in flood-prone areas, and the wider community. An event may be extreme in terms of its frequency, timing (during the year) or duration. Climate change has the potential to change flood characteristics through changing the volume and timing of precipitation, and by altering the partitioning of precipitation between snow and rain (Chapter 3). However, changes in catchment surface characteristics – such as land cover – and the river network can also lead to changes in the physical characteristics of river floods. The impacts of extreme flood events include direct effects on livelihoods, property, health, production and communication, together with indirect effects of these consequences through the wider economy. The magnitude of these impacts depends on what is exposed to the flood hazard, how sensitive this exposure is to loss or damage, and the ability to recover or react to flood events. Future changes in the impacts of flooding will therefore be influenced not only by changes in climate, but also by changes in catchment and river properties and, significantly, changes in exposure and sensitivity to flood loss.

There have been a large number of studies into potential changes in the flood frequency curve due to climate change (e.g. Cameron (2006), Lehner et al. (2006), Hirabayashi et al. (2008), Dankers and Feyen (2008; 2009), Kay et al. (2009): see Chapter 3). These studies have concluded that the estimated effects of climate change are highly dependent on the climate models used to define scenarios and, to a lesser extent, the methodologies used to link climate model information with hydrological models. Under some scenarios changes may be small – or the frequency of flooding may reduce – but under others there may be a substantial change in the frequency with which specific extreme events are exceeded. For example, Dankers and Feyen (2008) showed, under one scenario, that in parts of Europe the current 100-year event would be exceeded more frequently than once every 50 years. As with droughts, however, few studies have translated changes in flood *frequency* into changes in flood *impact*.

An early study in the US (Choi and Fisher, 2003) constructed regression relationships between annual flood loss and socio-economic and climate drivers, concluding that a 1% increase in average annual precipitation would, other things being equal, lead to an increase in annual national flood loss of around 6.5%. However, the conclusions are highly dependent on the regression methodology used, and the spatial scale of analysis. More sophisticated analyses combine estimates of current and future damage potential (as represented by a damage-magnitude relationship) with estimates of current and future flood frequency curves to estimate event damages and average annual damages (sometimes termed expected annual damage). For example, Mokrech et al. (2008) estimated damages under the current 10-year and 75-year events in two regions of England. Their published results combine fluvial and coastal flooding, but it is possible to draw two main conclusions from their work. First, the percentage change in cost was greater for the rarer event than the more frequent event. Second, the absolute value of impact, and therefore the percentage change from current impact, was found to be highly dependent on the assumed socio-economic change; in one region, event damage under one socio-economic scenario was, in monetary terms, between 4 and 5 times the event damage under another scenario. An even wider range in estimated *average annual* damage was found in the UK Foresight Future Flooding and Coastal Defence project (Hall et al., 2005; Evans et al., 2004) which calculated average annual damage in 2080 of £1.5 billion, £5 billion and £21 billion under similar climate scenarios but different socio-economic futures (current average annual damage was estimated at £1 billion). The Foresight project represented the effect of climate change on flood frequency by altering the shape of the flood frequency curve using expert judgement based on changes in precipitation as simulated using a number of climate models. The EU-funded PESETA project (Ciscar, 2008; Feyen et al., 2009) used a hydrological model to simulate river flows, flooded areas and flood frequency curves, from climate scenarios derived from regional climate models, but – in contrast to the UK Foresight project – assumed no change in economic development in flood-prone areas. Table 4-12 summarises estimated changes in the numbers of people affected by flooding (i.e. living in flood-prone areas) and average annual damage, by European region (Ciscar, 2008). There are strong regional variations in impact, with particularly large increases (over 200%) in central and eastern Europe; in parts of north eastern Europe, average annual flood damages decrease.

[INSERT TABLE 4-12 HERE
Table 4-12: Impact of climate change by 2071-2100 on flood risk in Europe (Ciscar, 2008). Note that the numbers assume no change in population or development in flood-prone areas.]

At the global scale, Kleinen and Petschel-Held (2007) estimated the numbers of people affected by increased flood risk with different rates of increase of global temperature. Their indicator of impact is the percentage of population living in river basins where the return period of the current 50-year return period event is reduced to return periods between 40 years (the 50-year flood is 1.25 times as frequent) and 10 years (the 50-year flood is 5 times as frequent). They used three climate models to define changes in climate. With an increase in global mean temperature of 2ºC (above late 20th century temperatures), between (approximately) 5 and 28% of the world's population would live in river basins where the current 50-year return period flood occurs at least twice as frequently.

4.4.2.2. Ecosystems

According to IPCC AR4 (see IPCC AR4 WG2, 4.4) the most sensitive ecosystems to extreme climate include desert, grassland and Savanna, Mediterranean ecosystem, forest and woodland, tundra and Arctic/Antarctic ecosystems, mountains, forest and woodland, fresh water wetland, lakes and river, oceans and shallow seas, due to extreme warm, drought, fire, pets and ENSO etc.

Desert biodiversity is likely to be vulnerable to climate change (Reid et al., 2005), with winter-rainfall desert vegetation and plant and animal species especially vulnerable to drier and warmer conditions (Lenihan et al., 2003; Simmons et al., 2004; Musil et al., 2005; Malcolm et al., 2006). In the Succulent Karoo biome of South Africa, 2,800 plant species face potential extinction as bioclimatically suitable habitat is reduced by 80% with a global warming of 1.5-2.7ºC above pre-industrial levels. Daytime in situ warming experiments suggest high vulnerability of endemic succulent (see Glossary) growth forms of the Succulent Karoo to high-end warming scenarios for 2100 (mean 5.5°C above current ambient temperatures), inducing appreciable mortality in some (but not all) succulent species tested within only a few months (Musil et al., 2005). [see also IPCC AR4 WG2, 4.4.2]

Ecosystem function and species composition of grasslands and savanna are likely to respond mainly to precipitation change and warming in temperate systems but, in tropical systems, CO2-fertilization and emergent responses of herbivory and fire regime will also exert strong control. Sahelian woody plants, for example, have shown drought-induced mass mortality and subsequent regeneration during wetter periods (Hiernaux and Turner, 2002). Climate change is likely to increase fire frequency and fire extent. Greater fire frequencies are noted in Mediterranean Basin regions (Pausas and Abdel Malak, 2004) with some exceptions (Mouillot et al., 2003). [see also IPCC AR4 WG2, 4.4.3]

Soil water content controls ecosystem water and CO2 flux in the Mediterranean Basin system (Rambal et al., 2003), and reductions are very likely to reduce ecosystem carbon and water flux (Reichstein et al., 2002). [see also IPCC AR4 WG2, 4.4.4]

Since the TAR, most DGVM models based on A2 emissions scenarios show significant forest dieback towards the end of this century and beyond in tropical, boreal and mountain areas, with a concomitant loss of key services. Species-based approaches suggest losses of diversity, in particular in tropical forest diversity hotspots (e.g., north-eastern Amazonia – Miles, 2002) and tropical Africa (Mc Clean et al., 2005). Climate change impacts on forests will result not only through changes in mean climate, but also through changes in seasonal and diurnal rainfall and temperature patterns (as influenced by the hydrologically relevant surroundings of a forest stand, e.g., Zierl and Bugmann, 2005). If climate warms and this ecotone becomes exposed to more droughts, insect outbreaks will become a major factor (Logan et al., 2003; Gan, 2004). Climate changes including El Niño events alter fire regimes in fire-prone regions such as Australia (Hughes, 2003;Williams et al., 2004b;Allen Consulting Group, 2005), the Mediterranean region (e.g., Mouillot et al., 2002; see also Section 4.4.4), Indonesia and Alaska (Hess et al., 2001), but also introduce fire into regions where it was previously absent (e.g., Schumacher et al., 2006). [see also IPCC AR4 WG2, 4.4.5]

Disturbances such as avalanches, rockfall, fire, wind and herbivore damage interact and are strongly dependent on climate (e.g., Peñuelas and Boada, 2003;Whitlock et al., 2003; Beniston and Stephenson, 2004; Cairns and Moen, 2004; Carroll et al., 2004; Hodar and Zamora, 2004; Kajimoto et al., 2004; Pierce et al., 2004; Schoennagel et al., 2004; Schumacher et al., 2004). [see also IPCC AR4 WG2, 4.4.7]

Current extreme climatic events provide an indication of potential future effects. For example, the warm-water phase of ENSO is associated with large-scale changes in plankton abundance and associated impacts on food webs (Hays et al., 2005), and changes to behaviour (Lusseau et al., 2004), sex ratio (Vergani et al., 2004) and feeding and diet (Piatkowski et al., 2002) of marine mammals. [see also IPCC AR4 WG2, 4.4.9]

Ecological surprises include rapid and abrupt changes in temperature and precipitation, leading to an increase in extreme events such as floods, fires and landslides, increases in eutrophication, invasion by alien species, or rapid and sudden increases in disease (Carpenter et al., 2005). This could also entail sudden shifts of ecosystems to less desired states (Scheffer et al., 2001; Folke et al., 2004; e.g., Chapin et al., 2004) through, for example, the exeedance of critical temperature thresholds, possibly resulting in the irreversible loss of ecosystem services, which were dependent on the previous state (Reid et al., 2005). [see also IPCC AR4 WG2, 4.4.10]

4.4.2.3. Food systems and food security

Changes in temperature and precipitation patterns will affect food production systems. High temperatures stresses can manifest themselves in different ways during the growth cycle of plants. During the vegetative period of development, higher temperatures will cause a more rapid rate of development, but more likely the response is linked with water shortage because of the increased rate in the use of soil water. This effect will be exaggerated if there is a shortage in soil water caused by limited rainfall or limited availability of irrigation water supplies. Ortiz et al. (2008) in an analysis of future wheat production in India based on projected climate scenarios found that there was a major shift in Indo-Gangetic Plains from a high potential, irrigated, low-rainfall mega-environment to a heat-stressed, irrigated, short-season production mega-environment. The significance of this shift is that this area currently accounts for 15% of the global wheat production and as much as 51% of the current area could be reclassified into this more stressful environment for wheat production causing a significant reduction in wheat production. These types of analysis need to be conducted for all of the food and feed growing regions of the world to determine the potential impact of climate change on production. These effects are due to the projected scenarios and do not include the potential impacts from extreme events.

Extreme events in temperature will have their greatest effect if they occur just prior to or during critical pollination phases of the crop. The impact is not universal across all crop species because of the duration and timing of the pollination phase of crop development and has been observed through numerous experimental studies throughout the world. Crop sensitivity and ability to compensate during later improved weather, will depend on the synchrony of anthesis in each crop: maize for example has a highly compressed phase of anthesis, while spikelets on rice and sorghum may achieve anthesis over a period of a week or more. Soybean, peanut, and cotton will have several weeks over which to spread the success of reproductive development. For peanut (and presumably other legumes) the sensitivity to elevated temperature for a given flower, extends from 6 days prior to opening (pollen cell division and formation) up through the day of anthesis. Therefore, several days of elevated temperature may affect fertility of many flowers whether still in their formative 6-day phase or just achieving anthesis. In addition the first 6 h of the day were more critical during which the pollen dehiscence, pollen tube growth and fertilization occur. (Hatfield et al, 2008)

High temperatures in rice, the reproductive processes that occur within 1-3 h after anthesis (dehiscence of the anther, shedding of pollen, germination of pollen grains on stigma, and elongation of pollen tubes) are disrupted by daytime air temperatures above 33ºC. Since anthesis occurs between about 9 to 11am in rice, exceeding such air temperatures may be already be common and may become more prevalent in the future. Pollination processes in other cereals maize and sorghum may have a similar sensitivity to elevated daytime temperature as rice. Rice and sorghum have the same sensitivity of grain yield, seed harvest index, pollen viability, and success in grain formation in which pollen viability and percent fertility is first reduced at instantaneous hourly air temperature above 33ºC and reaches zero at 40ºC. Diurnal max/min day/night temperatures of 40/30ºC (35ºC mean) cause zero yield. Extreme temperatures wil have negative impacts on grain yield. (Kim et al. (1996), Prasad et al. (2006))

Elevated temperatures above the optimum cause yield decreases due to temperature effects on pollination and kernel set in maize. Temperatures above 35ºC are lethal to pollen viability. In addition, the critical duration of pollen viability (prior to silk reception) is a function of pollen moisture content which is strongly dependent on vapor pressure deficit. There is limited data on sensitivity of kernel set in maize to elevated temperature, although in-vitro evidence suggests that the thermal environment during endosperm cell division phase (8 to 10 days post-anthesis) is critical. A temperature of 35ºC compared to 30ºC during the endosperm division phase dramatically reduced subsequent kernel growth rate (potential) and final kernel size, even if placed back in 30ºC. Temperatures above 30ºC increasingly damaged cell division and amyloplast replication in maize kernels and thus reduced grain yield. Leaf photosynthesis rate of maize has a high temperature optimum of 33 to 38ºC with minimal sensitivity of quantum efficiency to elevated temperature, although photosynthesis rate is reduced above 38ºC. An evaluation of high temperature effects on sweet corn in a controlled environment chamber, found the highest photosynthetic rate was at temperatures of 25/20 while at 40/35°C (light/dark) the photosynthetic rate was 50-60% lower. There was also a gradual decline in photosynthetic rate for each 1°C increase in temperature. These extreme events in temperature will negatively impact crop yield and will be increased in areas which are subjected to increased probability of variable precipitation. (Ben-Asher et al. (2008), Fonseca and Westgate (2005))

Analysis of the impact of climate change during the period from 1981 to 2005 in semiarid northwest region of China showed there was a change in phenology of wheat with an increase in crop yields at both the low altitude and high altitude locations (Xiao et al., 2008). They projected based on the expected warming trends a 3.1% increase in yields at the low altitude sites and a 4.0% increase at the high altitudes. Impact of climate change on rice yield in Japan was evaluated using the PRYSBI model (Process-based Regional scale Rice Yield Simulator with Bayesian Inference) with model parameters of the PRYSBI were calibrated with based on historical data on rice yield and climate variables in each prefecture of Japan and the model can reproduce yield by prefecture with the precision of 0.2t/ha (Yokozawa et al., 2009). In the PRYSBI, sterility and growth limitation due to extremely high and low temperature during yield formation period is explicitly simulated. In all regions, as temperature increases, inter-annual variability of rice yield is expected to increase due to the increase in occurrence of sterility caused by heat stress. This trend is especially significant in Tokai, Chubu, Kansai regions, where the intensification of the Pacific high pressure is expected to cause more frequent very hot summer under climate change. While the national average of rice yield will not change or slightly increase with the temperature increase smaller than 3 °C, the regional average of rice yield will decrease with larger temperature increase except in Hokkaido/Tohoku region. Shift of planting date is expected to be an effective adaptation in the north and east regions of Japan, while introduction of heat tolerant varieties will be favorable in the west and south regions of Japan. (Yokozawa et al., 2009)

Drought causes yield variation and in Europe the historical yield records show that drought is the primary cause of interannual yield variation (Hlavinka et al., 2009). Water supply for agricultural production will be critical to sustain production and even more important to provide the increase in food production required to sustain the world's growing population. With glaciers retreating due to global warming and El Niño episodes, the Andean region faces increasing threat on water supply. With most of the precipitation coming in 3-4 months, the glaciers plays a temporal buffer by stocking precipitations in ice and snow and redistribution of the water by melting during the dry season. The glaciers recession reduces the buffering role of the glaciers, hence inducing a double threat: more floods during raining season and more water shortage during the dry season. Physically, the glaciers are holding rocks and other debris. With retreating of glaciers, such debris are now exposed and could lead to debris flows after heavy rainfalls or after earthquakes. The recession of the glaciers also induces the formation of high altitude lakes and some of them include a risk of being suddenly released after earthquakes, of if an avalanche creates a GLOF. The risk of collapse of such dams can have drastic consequences. (Silverio and Jaquet, 2005; Vuille et al., 2008; Zemp, 2008)

The economies of many developing countries rely heavily on agriculture; dominated by small-scale and subsistence farming. People's livelihoods in this sector are especially exposed to weather extremes (Easterling, W and Apps, M, 2005). The majority of households produce maize in many African countries, but only a modest proportion sell it – the great majority eat all they produce. In Kenya for example, nearly all households grow maize, but only 36% sell it, with 20% accounting for the majority of sales. This pattern sees a growing inequality of income which is likely to continue as farms get smaller due to population growth and environmental degradation (FAO, 2009). Both such famers and their governments have limited capacity for recovery (Easterling, W and Apps, M, 2005). Farmers do not usually have insurance although micro insurance is increasingly available.

The initial obvious impact is a shortage of food for those entirely dependent on their own produce for their food supply, and those whose cash livelihood depends on their own food crops. Crop-failure is a key driver for rural urban migration, which is expected to be exacerbated under climate change. For example: since 1970, Malawi has faced increasing frequency and severity of drought and flood events, less seasonal rain and higher temperatures. A hybrid drought tolerant maize variety has been promoted, but requires expensive inputs such as chemical fertiliser, which is unaffordable for small holder farmers unable to find cash employment. These combined production factors create significant hardship for smallholder farmers (ActionAid, 2006). A more complex impact followed Cyclone Nargis in the Ayeyarwaddy delta region of Myanmar. The disaster's convergence with the global financial crisis has seen the rural economy collapse as credit has been withdrawn. Food security is again a significant concern (Stone, 2009).

Subsistence farmers who have a marginal existence under normal conditions, are probably the most severely impacted by climate and weather events. The most vulnerable to food price increases are poor, urban residents in food-importing developing countries; the landless poor and female-headed households are also particularly vulnerable (FAO, 2008). (Global food price increases are burdened disproportionally by low-income countries, where many people spend up to 50% of their income on food (OECD-FAO, 2008)). In some locations women and girls bear the initial brunt of food scarcity, which is both a result of, and contributes to, systemic gender inequality (Vincent et al., 2008).

4.4.2.4. Human Settlements, Industry and Infrastructure

Most urban centres in sub-Saharan Africa and in Asia have no sewers (Hardoy, Mitlin and Satterthwaite, 2001). Sanitation infrastructure is the main determinant of the contamination of urban floodwater with faecal material, presenting a substantial threat of enteric disease (Ahern et al., 2005). In Andhra Pradesh, India, a heat wave killed more than 1,000 people – mostly labourers working outside in high temperatures in smaller urban settlements (Revi, 2008).

Flooding (also leading to disease), landslides (UN/POP/EGM-URB/2008/16), Heatwaves (Kovats and Aktar 2008) are important hazards for this sector. It is well documented that, in most cities, the urban poor live in the most hazardous urban environments – for instance on floodplains or other areas at high risk of flooding or unstable slopes (Hardoy, Mitlin and Satterthwaite, 2001). Worldwide, about one billion live in informal settlements, and this proportion is growing at about twice the rate of formal settlements.

Climate change is likely to bring ever-increasing numbers of accidental deaths and serious injuries and increasingly serious damages to people's livelihoods, property, environmental quality and future prosperity – especially the urban poor in informal settlements (UN/POP/EGM-URB/2008/16).

A large proportion of those in informal settlements are especially susceptible to harm with limited ability to recover. Groups especially impacted include infants and older groups who are less able to cope with heat waves, and less able to escape floodwaters. Those who work outside without heat protection are also very vulnerable (UN/POP/EGM-URB/2008/16).

Poorer groups get hit hardest by this combination of greater exposure to hazards (e.g., a high proportion living on unsafe sites) with no or limited hazard-removing infrastructure, and high vulnerability due to makeshift housing with less capacity to cope due to a lack of assets, insurance, and marginal livelihoods, with less state support and limited legal protection. Low-income groups also have far less scope to move to less dangerous sites (UN/POP/EGM-URB/2008/16). Informal settlements are found in all regions, for example there are some 50 million people in such areas in Europe (UNECE 2009).

Coastal areas are among the world's most vulnerable to climate extremes, such as Sea Level Rise (SLR) and other events (e.g. tropical storms and cyclones and related storm surges), the intensity and frequency of which is projected to increase. Moreover, as the size/permanence of coastal communities and infrastructure has increased very significantly over recent decades, affecting the ability of coastal systems to respond effectively to SLR and other extreme climate events, the exposure of coastal communities/assets is growing at an ever increasing rate. The severity of the impacts will depend on the rate of SLR, with rapid SLR likely to impact more severely natural systems and amplify the potential economic losses/costs of adaptation. Coastal landforms (beaches, seacliffs, estuaries, lagoons, deltas) are highly likely to suffer increased rates of erosion, while coastal ecosystems, such as coastal wetlands, coral reefs and seagrasses may also be severely affected. Economic activities in coastal areas that may be at threat from SLR and other extreme events include among others transportation (ports and other coastal infrastructure, e.g. airports, railways and roads) and tourism (due to beach erosion and threat to coastal tourism infrastructure). Small island states, particularly SIDS, are likely to be very severely affected; in some cases, and depending on the SLR scenarios, there might even be a need for permanent population evacuation. In some coastal settings and landforms (e.g. deltas and coastal wetlands), SLR will be further exacerbated by (i) land subsidence triggered by natural processes (e.g. sediment auto-compaction) and/or human-induced interference (e.g. extraction of groundwater/hydrocarbons); (ii) diminishing sediment supply due e.g. to river damming and other management schemes. (The Copenhagen Diagnosis (2009), Lenton et al. (2009), Cai et al. (2009), Ericson et al. (2006), Woodroffe (2008))

Slope failure risk is expected to increase in future at many places, since increase in frequency/intensity of strong rainfall is projected by climate models. Slope failure risk in Japan under the changed precipitation was evaluated for the period around 2050 with spatial resolution of 1km^2. With using spatial data on daily precipitation, geography, geology, and landuse, slope failure probability in each grid cell was calculated first. Then, with multiplying economic value of each grid cell, expected economic loss due to slope failure (return period: 50 years) under the changed climate condition was calculated. Grid cells with high slope failure risk is expected to distribute from the top to the skirts of mountainous area. Especially, in the south Hokkaido region, the coast of Japan Sea from Hokuriku region to Chugoku region, and median tectonic zone from Tokai region through Shikoku region, increase in slope failure risk is most significant. In some prefectures (Tochigi, Gumma, Saitama, Toyama, Ishikawa, Fukui, Hiroshima, and Kagoshima), area with high expected economic loss due to slope failure concentrates. Therefore, prioritized implementation of adaptation measures will be needed in those prefectures. (Kawagoe and Kazama,2009)

Throughout most of the 20th century, North Atlantic oscillation (NAO) correlates with winter precipitation and river flow regimes for the three main international Iberian river basins, namely the Douro (north), the Tejo (centre) and the Guadiana (south). The impact of the NAO on winter river flow was quantified in terms of total Spanish potential hydroelectricity production. The important control exerted by the NAO and the recent positive trend in the NAO index contribute to a significant decrease in the available flow, and therefore, hydropower production in the Iberian Peninsula. (Trigo et al., 2004)

Climate warming leads to permafrost degradation, the 40-80-cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost (Sherstyukov, 2009). Changes in permafrost damage the foundations of buildings and disrupt the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10-12% in 20-25 years, with permafrost borders moving 150-200 km northeast (Anisimov et al., 2004).

Approximately 10% of global GDP is spent on recreation and tourism, being a major source of income and foreign currency in many developing countries (Berrittella et al, 2006). The tourism sector is highly sensitive to climate, since climate is the principal driver of global seasonality in tourism demand (Maddison, 2001; Lise and Tol, 2002). It is also widely recognized that extreme weather events like floods, excessive heat, and windstorms, affect human life and environments more than changes in the mean climate, and therefore a potential increase in extreme events may play an important role on tourist decisions (Yu et al., 2009).

The distribution of global tourism is expected to shift polewards due to increased temperatures associated with climate change (Amelung et al., 2007). Parts of the Mediterranean, a very popular summer tourist spot, may become too hot in summer but more appealing in spring and autumn (Hein et al., 2009). More temperate tourist destinations are predicted to become more attractive in summer. Length and quality of climate-dependent tourism seasons (e.g., sun-and-sea or winter sports holidays) are expected to change in different areas, with considerable implications for competitive relationships between destinations and therefore the profitability of tourism enterprises (Amelung et al, 2007; Bigano et al, 2007). A changing trend on climate extremes will impact the tourism sector (Scott et al., 2008), and requires examination of nature and severity of physical risks impacting tourism resources (e.g. biodiversity, water supply, snow reliability) and infrastructure (e.g., coastal resorts), business and regulatory risks (e.g., changes in insurance coverage), or market risks (e.g., changes in international competitiveness linked with comfort temperatures).

There are three broad categories of climate extreme impacts that can affect tourism destinations, their competitiveness and sustainability: (a) direct impacts on tourist infrastructures (hotel, access roads, etc), on operating costs (heating-cooling, snowmaking, irrigation, food and water supply, evacuation and insurance costs), on emergence preparedness requirements, and on business disruption (e.g., sun-and-sea or winter sports holidays); (b) indirect environmental change impacts of extreme events on biodiversity and landscape change (eg. coastal erosion), which are likely to be largely negative on quality of tourism attractions and perception of a location; and (c) tourism adverse perception to particular touristic regions after occurrence of the extreme event itself, questioning a tourist destination in a longer-term (annual basis). It is not unlike that as result of adverse weather conditions or occurrence of an extreme event is produced a reduced confidence in the area by tourists during the follow up season. Apart from extreme events, long-term climate change effects (e.g. sea level rise and coral bleaching) may produce large impacts on some tourist destinations. Capacity to recover is likely to depend on the degree of dependence on tourism with diversified economies being more robust (Ehmer and Heymann, 2008). Low lying coastal areas and areas currently on the edge of the snow line may have limited alternatives. Some ski resorts will be able to adapt using snowmaking which has become an integral component of the ski industry in Europe and North America, although at expenses of high water consumption (Elsasser and Bürki, 2002). The complex nature of the interactions that exist between tourism, the climate system, the environment and society, makes difficult to isolate the direct observed impacts of climate change upon tourism activity (Rezenweig et al., 2007).

In some regions, the main impact of extreme events in tourism will be decline in revenue, with loss of livelihoods for those working in the sector, and provokes mistrust on tourism and operating companies in the affected area (Hamilton et al., 2005; Scott et al., 2008; Hein et al., 2009). Regional projections in the frequency or magnitude of certain weather and climate extremes (e.g. heat waves, droughts, floods, tropical cyclones; see chapter 3) provide a qualitative understanding of regional impacts on tourism activities (Table 2). The vulnerable hotspot regions in terms of extreme impacts of climate change on tourism includes the Mediterranean, Caribbean, small island of the Indian and Pacific oceans, Australia and New Zealand, (see Figure 4-12; Scott et al., 2008). Direct and indirect effects of extremes in these regions will vary greatly with location (Gössling and Hall, 2006a,b; Wilbanks et al., 2007).

[INSERT FIGURE 4-12 HERE:
Figure 4-12: Climate change vulnerability hotspots in the tourism sector (Scott et al., 2008).]

A potential range of climate extreme impacts on tourism regions and activities can be pointed out.

Tropics: Increase cyclone intensity, with wind speeds expected to increase up to 20% (Preston et al, 2006). In the Caribbean, reduced tourist amenity as beaches erode with sea level rise, and degraded snorkeling and scuba activities due to coral bleaching (Uyarra et al, 2005). Increasing incidence of vector-borne diseases as result of increased temperatures and humidity will all impact tourism to varying degrees in the tropics (Tong and Hu, 2001). For example, Ross River fever outbreaks in Cairns, Australia, have a significant impact on the local tourist industry.

Small island states are dependent on tourism, and the tourism infrastructure that lies on the coast is threatened by climate change (Berrittella et al., 2006). Sea level rise since 1880 with an average rate of 1.6 mm/year (Bindoff and Willebrand 2007) poses in risk many touristic resorts of small islands in the Pacific and Indian oceans (Scott et al., 2008).

Alpine regions: Warming temperatures will raise the snow line elevation (Elsasser and Bürki, 2002; Scott et al., 2006). In Switzerland only 44% of ski resorts will be above the 'snow-reliable' altitude by approximately 2030, as opposed to 85% today, whereas in Austria, many ski areas will suffer from reduced snow reliability (Elsasser and Bürki, 2002).

Mediterranean countries: More frequent heat waves and tropical nights in summer may lead to exceeding comfortable temperature levels and reduce the touristic flow by 2060 (Hein et al., 2009). Increase on travelling and holidays during transition seasons (spring and autumn; Perry, 2003, Esteban Talaya et al., 2005). Change on the tourist behavior, decreasing the stay period, delaying the travel decision, changing the selection of destination. Northern European countries are expected to become relatively more attractive closing the gap on the currently popular southern European countries (Hamilton et al., 2003)

There are major regional gaps in understanding how climate change may affect the natural and cultural resources in Africa and South America that prevents for further insight on their impacts on tourism activities (Scott et al., 2008).

[INSERT TABLE 4-13 HERE
Table 4-13: Identification of extreme impacts affecting the tourism sector by regions. Sources: IPCC 2007; Ehmer and Heymann, 2008; Scott et al., 2008]

4.4.2.5. Human Health, Well-Being, and Security

The largest research gap is a lack of information on impact outcomes themselves in developing countries in general. This includes the mortality/morbidity data and information on other contributing factors such as nutritional status or access to safe water, medical facilities. Only limited number of places in developing countries has been investigated. As Byass (2009) showed, among 731 of health and climate change subjects, only 31 (4.2%) was on Africa. The lack of information is inherent in developing countries, where public health infrastructure is poor and where the impact would be hardest due to both severe hazards and lower coping capacity. Within the developing countries, lower socio-economic status usually worsens the vulnerability.

Research conducted include those of heat wave, flood, extreme weather (heavy rain followed by drought, for example), and cyclone. These three extreme weather events can occur even if climate change did not occur. However, the frequency may be higher when the global warming occurs.

Heat waves have affected developed countries, as exemplified by 2003 European heat wave. Most people do not think that heat extremes can claim casualties in tropical countries. Hajat et al. (2005) reported, however, that heat extremes affected Delhi, India. This example suggests that the effect of heat extremes on developing countries would be underestimated. Hajat et al. (2005) also demonstrated that the mortality pattern due to heat in Delhi was different from that of other developed countries. In this regard, more researches should be conducted in developing countries.

Floods directly cause deaths, injuries, followed by infectious diseases (such as diarrhea) and malnutrition due to crop damage. In Dhaka, Bangladesh, the severe flood in 1998 caused diarrhea during and after the flood, and the risk of non-cholera diarrhea was higher for those with lower education level and not using tap water (Hashizume M et al., 2008). In 2002 report, WHO assumed that countries with 6,000+ US dollars of per capita GDP. On the contrary, diarrhea as well as injuries occurred after a 2002 flood in Germany, one of the developed countries (Schnitzler J, et al., 2007). It may not always be true, but floods can increase the patients of malaria in some cases. In Mozambique, the incidence of malaria increased by 4 to 5 times after the flood in 2000 (compared with non-disaster periods) (Kondo, et al., 2002).

In 1991, 138,000 people died due to a cyclone in Bangladesh. The risk factors for mortality were those who did not reach shelters, those under 10 years of age, and women older than 40 years (Bern C et al, 1993). The authors discussed that more effective warning system and better access to cyclone shelters were necessary.

Drought is a trigger for human ignited forest fires leading to widespread deforestation and carbon emissions. (Field et al. (2009), Van Der Werf et al. (2008), Costa and Pires (2009), D'almeida et al. (2007), Phillips et al. (2009)).

In western part of North America in the recent 30 years the area affected by forest fires increased twofold, and in the coming 100 years under expected warming it will further increase by 80%. Modeling of forest fires in Siberia shows that the temperature rise from 9,80C to 15,30C may result in the fact that a number of years with severe fires will increase twofold, an area affected by forest fires will be increasing by almost 15% per year and timber resources will reduce by 10%.

4.5. Regionally Based Aspects of Vulnerability, Exposures, and Impacts

4.5.1. Introduction and Overview

These regional sections are about climate change and climate-related disasters within the context of other issues and trends.

The material should deal with extreme climate events and impacts. In doing this it would consider exposure of humans and their activities to the climatic phenomenon, the vulnerability of what is exposed to the phenomenon and the resulting impacts. There is a strong interest in the observed trends in climatic events, exposure, vulnerability and impacts and the role of climate change in any observed trends.

Each region will likely have its own priorities and these will help structure the individual sections.

4.5.2. Africa

Africa is the second largest continent, with area of 30,221,532 km^2, one third of which is covered by drylands (Sahara, Namib). The estimated total population in Africa now (2010) is around one billion. The Africa’s climate ranges from the humid tropics to the hyper-arid Sahara. Climate exerts a significant control on the day-to-day economic development of Africa, particularly in traditional rain fed agriculture and pastoralism, and water resources, at all scales – from regional, to local and household scales. Observed warming trends are consistent over the continent with an average increase of 0.74°C over the period 1906-2005 (see Christensen et al., 2007), although these changes are not uniform over the continent (Boko et al., 2007). In general terms, minimum temperatures registered a major increase during the last decade, whereas minor increases were observed in maximum or mean temperatures (Conway et al., 2004; Kruger and Shongwe, 2004). Climate model projections estimate a temperature increase of 0.2°C per decade over the 21st century within the range of the SRES scenarios (Christensen et al., 2007). The expected warming trends will mean as direct impact projections (Boko et al., 2007): an increase of arid and semi-arid land, increase in the number of people exposed to increased water stress, decrease of yield from rain-fed agriculture in some countries, and a widespread increase in evapotranspiration and reduction in runoff and in ecosystem net primary production (Delire et al. 2008).

Extreme events, such as droughts and floods, are known to have a major human and ecological impact in this continent. However, there is still limited information available on extreme events observed frequency and projections (Christensen et al., 2007, Chapter 3 this SREX report), despite frequent reporting of such events, including their impacts.

[INSERT FIGURE 4-13 HERE:
Figure 4-13: People affected by natural disasters from 1971-2001.]

Droughts and heat waves
The number of hot spells has increased in southern and western Africa over last decades, together and the number of extremely cold days has decreased (New et al., 2006). Droughts have mainly affected the Sahel, the Horn of Africa

and Southern Africa, particularly since the end of the 1960s (Richard et al., 2001; L'Hôte et al., 2002; Brooks, 2004; Christensen et al., 2007; Trenberth et al., 2007).

One of the main consequences of a multi-year drought periods is severe famine, such as the one associated with the drought in the Sahel in 1980s, causing many casualties and high economic losses. It is estimated that one-third of the people in Africa live in drought-prone areas and are vulnerable to the direct impacts of droughts (famine, death of cattle, soil salinisation), cholera and malaria (Few et al., 2004). Adaptation strategies that are applied by pastoralists in times of drought include the use of emergency fodder, culling of weak livestock for food, and multi-species composition of herds to survive climate extremes. During drought periods, pastoralists and agro-pastoralists change from cattle to sheep and goat husbandry, as the feed requirements of the latter are lower (Seo and Mendelsohn, 2006b). The pastoralists' nomadic mobility reduces the pressure on low-capacity grazing areas through their cyclic movements from the dry northern areas to the wetter southern areas of the Sahel (Boko et al., 2007). However, consecutive dry years with widespread disruption are reducing the ability of the society to cope with droughts by providing less recovery and preparation time between events (Adger, 2002). Moreover, land desertification and agricultural disruption together with shoreline erosion and coastal flooding, results from climate change, is projected to drive human migration.

Extreme rainfall events and floods

In parts of southern Africa, a significant increase in heavy rainfall events has also been observed, including evidence for changes in seasonality and weather extremes (Groisman, 2005; New et al., 2006). In southern Africa, where no long-term rainfall trend has been noted, increased inter-annual variability has been observed in the post-1970 period, with higher rainfall anomalies and more intense and widespread droughts reported (e.g., Richard et al., 2001; Fauchereau et al., 2003). Further north, in the Sahelian area, a sixty years rainfall record indicate, along a West-East transect, a trend towards an increase in drier years in the western regions (Ali and Lebel, 2008), whereas, specially during 1993-2006, a higher proportion of wet years is being registered in eastern Sahel (Lake Chad area).

Even countries located in dry areas have not been flood-free. In the arid and semi-arid areas of Horn of Africa countries, extreme rainfall events are often associated with a higher risk of vector- and epidemic diseases as malaria, dengue fever, cholera, Rift Valley fever (RVF), and hantavirus pulmonary syndrome (Anyamba et al., 2006; McMichael et al., 2006). This arthropod-borne viral disease (Geering et al., 2002) affects both humans and domestic ruminants. The periods of extreme rainfall and recurrent floods seem to correlate with El Niño/Southern Oscillation (ENSO) events (e.g. 1982-63, 1997-98, 2006-07). When such events occur, important economic and human losses result. In 2000, floods in Mozambique, particularly along the Limpopo, Save and Zambezi valleys, resulted in 700 reported deaths and about half a million homeless. The floods had a devastating effect on livelihoods, destroying agricultural crops, disrupting electricity supplies and demolishing basic infrastructure (Osman-Elasha, 2006). However, floods can be highly beneficial in African drylands (e.g. Sahara and Namib deserts) since the produced floodwaters infiltrate and recharge alluvial aquifers along ephemeral river pathways, extending water availability to dry seasons and drought years (Morin et al., 2009; Benito et al., 2010), and supporting riparian systems and human communities (e.g. Walvis Bay in Namibia with population 65,000).

The water sector is strongly influenced by, and sensitive to, periods of prolonged climate variability in a continent with limited water storage infrastructures. Natural water reservoirs such as lakes have experienced high interannual water level fluctuations, in particular since the 1960s, probably owing to periods of intense droughts followed by increases in rainfall and extreme rainfall events in late 1990s (e.g., in Lakes Tanganyika, Victoria and Turkana; see Riebeek, 2006). Large changes in hydrology and water resources linked to climate variability have led to water stress conditions to human and ecological systems in southern Africa (Schulze et al., 2001; New, 2002), south-central Ethiopia (Legesse et al., 2003), Kenya and Tanzania (Eriksen et al., 2005) and more wider, over the continent (de Wit and Stankiewicz, 2006; Nkomo et al., 2006). In terms of water availability, 25% of the contemporary African population experience high water stress, whereas 69% of the population live under conditions of relative water abundance (Vörösmarty et al., 2005). However, this relative abundance does not take into account access to safe drinking water and sanitation, which effectively reduces the quantity of freshwater available for human use. Despite the considerable improvements in access to freshwater in the 1990s, only about 62% of the African population had access to improved water supplies in 2000 (WHO/UNICEF, 2000).

Dust windstorms
Atmospheric dust is a major element of the Saharan and Sahelian environments. The Sahara Desert is the world's largest source of airborne mineral dust, that is transported large distances, traversing northern Africa and adjacent regions and depositing dust in other continents (Osman-Elasha, 2006, Moulin et al., 1997). Dust storms have negative impacts on agriculture, eroding fertile soil, uprooting of young plants, burying water canals, houses and other properties, and causing respiratory problems. Meningitis transmission, associated with dust in semi-arid conditions and overcrowded living conditions, may increase with climate change as arid and dusty conditions spread across the Sahelian belt of Africa. (DFID, 2004).

Adaptation
Adaptation strategies that are applied by pastoralists in times of drought include the use of emergency fodder, culling of weak livestock for food, and multi-species composition of herds to survive climate extremes. During drought periods, pastoralists and agro-pastoralists change from cattle to sheep and goat husbandry, as the feed requirements of the latter are lower (Seo and Mendelsohn, 2006b). The pastoralists' nomadic mobility reduces the pressure on low-capacity grazing areas through their cyclic movements from the dry northern areas to the wetter southern areas of the Sahel (Boko et al., 2007). However, consecutive dry years with widespread disruption are reducing the ability of the society to cope with droughts by providing less recovery and preparation time between events (Adger, 2002).

African women are particularly known to possess indigenous knowledge which helps to maintain household food security, particularly in times of drought and famine.

4.5.3. Asia

Destructive extreme events are commonplace in Asia. Changes (mostly increases) in the frequency and/or intensity of extreme weather events in Asia have been reported (Cruz et al., 2007).

Temperature extremes
Significantly longer heat wave duration has been observed in many countries of Asia, as indicated by pronounced warming trends and several cases of severe heat waves (Lal, 2003; Zhai and Pan, 2003; Ryoo et al., 2004; Batima et al., 2005a; Cruz et al., 2006; 2007; Tran et al., 2005). Increase of heat wave duration and severity was observed, among others, in Asian part of Russia, Mongolia, China, Japan, India, also decreases of cold extremes (cold waves) were noted (e.g., in Mongolia and Japan).

During 1955–2007 averaged over the Asia-Pacific Network (APN) region, annual frequency of cool nights (days) has decreased by 6.4 days/decade (3.3 days/decade), whereas the frequency of warm nights (days) has increased by 5.4 days/decade (3.9 days/decade). The change rates in the annual frequency of warm nights (days) over the last 20 years (1988–2007) have exceeded those over the full 1955–2007 period by a factor of 1.8 (3.4). Averaged over the APN region, annual mean maximum and minimum temperatures have increased by 0.17 °C/decade and 0.24 °C/decade since the mid-1950s, respectively (Gwangyong Choi *et al.*, 2009).

In Japan, the numbers of days with abnormally low air temperature decreased in recent decades and those with extremely high air temperature (>35°C) strikingly increased (Kurihara 2007). In the summer of 2003, the subtropical high was much stronger than normal and extended further west covering most of southern China for a long period of time. This led to severe heat wave with many hot days over that region. (Zhang *et al.,* 2008)

Rising temperatures and extreme weather events caused decline of the crop yield in many countries of Asia and adversely affected human health (Cruz et al., 2007).

Droughts
Increasing frequency and intensity of droughts has been observed in many parts of Asia, causing water shortage, crop failures, mass starvations, and wild fire. In Mongolia, in 1999-2002, a drought affected 70% of grassland and killed 12 million livestock. Increased droughts are attributed largely to a rise in temperature, particularly during the

summer and normally drier months, and during ENSO events (Duong, 2000; PAGASA, 2001; Lal, 2002, 2003; Batima, 2003; Gruza and Rankova, 2004; Natsagdorj et al., 2005). The number of days without precipitation show a rising trend in Japan (Kimoto et al. 2005).

Drought has significant adverse effect on the socioeconomic, agricultural, and environmental conditions. During drought, severe water-scarcity results in a region due to insufficient precipitation, high evapotranspiration, and over-exploitation of water resources and/or combination of these parameters (Bhuiyan *et al.,* 2006).

A study on esophageal cancer (EC) mortality rate and selected climate variables showed that high EC mortality mostly occurred in areas with high Drought Index. Correlation and regression analyses also show weak negative correlation between precipitation and EC mortality ($p<0.001$), and weak positive correlation between Drought Index and EC mortality ($p<0.001$). The study suggests that drought plays a role in the occurrence and development of EC in China, however, other environmental, biological and genetic factors should not be ignored (Kusheng Wu *et al.,* 2007)

About 15% (23 million ha) of Asian rice area experiences frequent yield loss due to drought (Widawsky and O'Toole, 1990). The problem is particularly severe in Eastern India, with more than 10 million ha of drought-prone fields (Pandey et al., 2000). Even when the total rainfall is adequate, shortages at critical periods reduce yield (Kumar *et al.,* 2007).

Keil *et al.* (2008) summarized that crop production in the tropics is subject to considerable climate variability that is mostly attributable to the El Niño-Southern Oscillation (ENSO) phenomenon (Salafsky 1994; Amien et al. 1996; Datt and Hoogeveen 2003). In Southeast Asia, El Niño is associated with comparatively dry conditions: 93% of droughts in Indonesia between 1830 and 1953 occurred during El Niño years (Quinn et al., 1978). In four El Niño years between 1973 and 1992, the average annual rainfall amounted to only around 67% of the 20 year average in two major rice growing areas in Java, Indonesia, causing a yield decline of approximately 50% (Amien et al. 1996). There is evidence that, in concert with global warming, the frequency and severity of extreme climatic events will increase during the twenty-first century, and the impacts of these changes will notably hit the poor (McCarthy et al. 2001).

Lowland rice production in the Mekong region is generally low because crops are cultivated under rainfed conditions and often exposed to drought. In Cambodia, severe drought that affect grain yield mostly occurs late in the growing season, and longer duration genotypes are more likely to encounter drought during grain filling (Tsubo *et al.,* 2009).

Intense precipitation and floods

Generally, there has been an increase in frequency and/or amplitude of heavy rains and floods, in number of days with high-intensity precipitation in many parts of Asia, e.g. in West and South China, Japan, Western Asian Russia, South-East Asia (Vietnam, Philippines, Cambodia), but not ubiquitously. Increase in heavy precipitation has caused severe floods, landslides, and debris and mud flows, even in some areas where the number of rainy days and total annual amount of precipitation decreased (Khan et al., 2000; Shrestha et al., 2000; Izrael and Anokhin, 2001; Mirza, 2002; Kajiwara et al., 2003; Lal, 2003; Min et al., 2003; Ruosteenoja et al., 2003; Zhai and Pan, 2003; Gruza and Rankova, 2004; Zhai, 2004). However, in some areas the frequency of extreme rainfall has exhibited a decreasing tendency (Manton et al., 2001; Kanai et al., 2004) – e.g. there has been a decrease in extreme precipitation in Northern China. Over Siberia, there has been a decrease in heavy rains but 50-70% increase in surface runoff.

There are no systematic, regional trends over the study period in the frequency and duration of extreme precipitation events in Asia-Pacific Network. Statistically significant trends in extreme precipitation events are observed at fewer than 30% of all weather stations, with no spatially coherent pattern of change, whereas statistically significant changes in extreme temperature events have occurred at more than 70% of all weather stations, forming strongly coherent spatial patterns (Gwangyong Choi *et al*., 2009).

Significant changes in precipitation over the Yangtze River Basin were found by (Tong Jiang, *et al.,* 2008). Changes in the monthly precipitation in spring and summer, from April to August, some of which are statistically significant, are of direct importance to seasonal flood hazard. The significant precipitation rise detected in June, July, and August tends to aggravate the flood hazard. More precipitation falls in intense events at the expense of moderate and weak events. The results by Ning Liang *et al.* (2009) for South China show that both the annual and summer extreme precipitation events have obvious inter-decadal variations and have increased significantly since the early 1990s.

Analysis of daily rainfall data over central India shows significant rising trend in the frequency and the magnitude of extreme rain events and significant decreasing trend in the frequency of moderate events during the monsoon seasons from 1951 to 2000. A substantial increase in hazards related to heavy rain is expected over central India in the future (Goswami *et al.,* 2006).

Among most dramatic climate extremes are floods jeopardizing large areas of Bangladesh, China and India, and causing high human and material losses, e.g. 30 billion US$ and material damage in excess of 3500 during 1998 floods in China.

As noted in (Ministry of Environment and Forest Government of the People's Republic of Bangladesh, 2005), flood in Bangladesh is a frequently normal recurrent phenomenon. Four types of flooding occurring in Bangladesh are: flash floods caused by overflowing of hilly rivers in eastern and northern Bangladesh (in April-May and in September-November); rain floods caused by drainage congestion and heavy rains; monsoon floods in the flood plains of major rivers (during June-September) and coastal floods due to storm surges. In a normal year, 20-25% of the country is inundated by river spills and drainage congestions. Approximately 37%, 43%, 52% and 60% of the country is inundated with floods of return periods of 10, 20, 50 and 100 respectively. About 1.32 m ha of cropland is highly flood-prone and about 5.05 m ha moderately flood-prone. Devastating floods of 1987, 1988 and 1998 inundated more than 60% of the country. The 1998 flood alone caused 1,100 deaths, inundated nearly 100,000 sq-km, rendered 30 million people homeless, damaged 500,000 homes and caused heavy losses to infrastructure.

Significant upward trends in the discharge of the River Yangtze in summer (flood season) months in the middle and lower regions were also detected (Tong Jiang *et al.,* 2008). Annual events of peak lake stage and of severe floods have increased dramatically during the past few decades in Poyang Lake, South China. This trend is related primarily to levee construction at the periphery of the lake and along the middle of the Changjiang (Yangtze River), which protects a large rural population. These levees reduce the area formerly available for floodwater storage resulting in higher lake stages during the summer flood season and catastrophic levee failures. The most extreme floods occurred during or immediately following El Niño events (Shankman *et al.,* 2006).

The number of days with heavy rain over 100 mm or 200 mm show a rising trend in Japan (Kurihara 2007). Owing to meteorological and topographical characteristics, flood disasters caused by heavy rains occur frequently in Japan. About 70% of the land is mountainous and covered with forests. Rivers in Japan are generally short and steep, causing flash flooding with high concentrated peak discharges soon after an intense rainfall. The remaining 30% of the land is mostly alluvial plains where housing, farming and industries are densely concentrated, consequently increasing the vulnerability to flood disasters. The majority of the population lives in densely populated areas in downstream alluvial plains, forming mega-cities such as Tokyo and Osaka, where highly valued assets are concentrated. Thus, Japan inevitably suffers serious socio-economic damage once flood disasters occur (Ikeda *et al.,* 2006).

As reported by National Environment Commission in Royal Government of Bhutan (2006), all the major rivers in Bhutan originate from glaciers and glacial lakes of the higher Himalayas. Two dozens of glacial lakes are potentially dangerous. Not until the 1994 Glacial Lake Outburst Floods (GLOF) was this danger taken seriously. Now it is recognized that the Raphstreng and Thorthormi glaciers and lakes could become dangerous in about a decade unless mitigation measures are taken. The worst case scenario being that a combined GLOF of these two lakes could result in a flow of over 53 million cubic meters of water - that is more than twice the volume of the 1994 GLOF.

Tropical cyclones

Recent studies indicate that the frequency and intensity of tropical cyclones originating in the Pacific have increased over the last few decades (Fan and Li, 2005). In contrast, cyclones originating from the Bay of Bengal and Arabian

Sea have been noted to decrease since 1970 but the intensity has increased (Lal, 2001). In both cases, the damage caused by intense cyclones has risen significantly in the affected countries, particularly India, China, Philippines, Japan, Vietnam and Cambodia, Iran and Tibetan Plateau (PAGASA, 2001; ABI, 2005; GCOS, 2005).

An increase of 10 to 20%in tropical cyclone intensities for a rise in sea-surface temperature of 2 to 4°C relative to the current threshold temperature is likewise projected in East Asia, South-East Asia and South Asia (Knutson and Tuleya, 2004). Amplification in storm-surge heights could result from the occurrence of stronger winds,with increase in sea-surface temperatures and low pressures associated with tropical storms resulting in an enhanced risk of coastal disasters along the coastal regions of East, South and South-East Asian countries. The impacts of an increase in cyclone intensities in any location will be determined by any shift in the cyclone tracks (Kelly and Adger, 2000).

Other climate disasters

Grassland fire disaster is a critical problem in China due to global warming and human activity (Su *et al.*, 2004; Zhang *et al.*, 2006). The northwestern and northeastern China face more challenges for mitigation of grassland fire disasters than other regions due to broad territory combined with the effects of complex physiognomy. According to statistical analysis of historical data of grassland fire disaster from 12 northern China provinces between 1991 and 2006, grassland fire disasters have been increasing gradually with economic development and population growth. The increased grassland fire disasters had significant impacts on the national stockbreeding economy (Liu *et al.*, 2006).

4.5.4. Europe

Introduction

Europe has higher population density and lower birth rate than any other continent. There is a tendency for the population to decrease and to become aged. Life expectancy is high and increasing and child mortality is low and decreasing. Europe has warmed up more than global mean in the last hundred years (+0.90ºC vs 0.74ºC) and climate projections in both SRES A2 and B2 show warming in all seasons for the future (A2: 2.5 to 5.5ºC; B2: 1 to 4ºC, IPCC, 2007). Precipitation trends are more spatially variable with large north-south differences. Mean winter precipitation is increasing in most of Atlantic and northern Europe (Klein Tank et al., 2002), a key driver on floods particularly when associated with snow-melting from mountain areas (Benito et al., 2005). In the Mediterranean area, yearly precipitation trends are negative in the east, while they are non-significant in the west (Norrant and Douguédroit, 2006). Climate change involves losses and gains on natural resource and economic sectors basis. In the north, agriculture is temperature-limited and benefiting of climate change. In the south, agriculture is precipitation-limited and is adversely affected by climate change.

Heat waves

Summer heat waves have already become increasingly frequent in summer in most of Europe (Della-Marta et al., 2007) and have affected vulnerable segments of European society. During the 2003 heat wave, several tens of thousands of additional heat-related deaths were recorded in countries of southern Europe (see case study on 2003 heat wave). Urban heat island poses an additional risk to urban inhabitants, especially old, ill, and lonely. There is a mounting concern about increasing heat intensity in major European cities (e.g. London, Wilby, 2003a), since 25% of European population live in urban areas exceeding 750,000 inhabitants (UN, 2004).

Droughts and wildfires

Drought risk is a function of frequency, severity, and spatial extent of dry spell and the vulnerabity and exposure of population and economic activity. A clear trend in hydrological drought over the 20th century cannot be ubiquitously found (De Wit et al., 2007, Hisdal et al., 2001), and where it occurs (e.g. Iberian rivers) it cannot be attributed to climate change. Significant increase of dry spells has been observed in East Germany over the last five decades (Krysanova et al., 2008). However, climate model projections point out to a likely increase of drought risk in southern and central Europe (e.g., Semenov and Bengtsson, 2002; Voss et al., 2002; Räisänen et al., 2003, 2004; Frei et al., 2006). Increasingly pronounced low flow and drought conditions in Central Europe are projected (Hattermann et al., 2008, 2010; Huang et al., 2010). In sub-Aalpine areas, flow regime changes towards a nivalpluvial type with more pronounced low flow conditions in summer, and more pronounced high flow periods in winter.

Forest fire danger (length of season, frequency and severity) is very likely to increase in the Mediterranean (Santos et al., 2002; Pausas, 2004; Moreno, 2005; Pereira et al., 2005; Moriondo et al., 2006), where it may lead to increased dominance of shrubs over trees (Mouillot et al., 2002), but also in central, eastern and northern Europe (Goldammer et al., 2005; Kellomäki et al., 2005; Moriondo et al., 2006). This, however, does not translate directly into increased fire occurrence or changes in vegetation (Thonicke and Cramer, 2006).

The amount of water resources demanded by tourism may be in conflict with other needs along the Mediterranean, particularly during summer, when population is tripled by arrival of tourists, and the per capita water consumption grows to 350 litres/day, in comparison to the European mean of 150-200 litres/day. This economic activity is highly vulnerable to droughts, although due to the high economic revenues, adaptation has improved capability on water supply system to meet summer peak demands.

Coastal flooding

Coastal flooding is an important natural disaster, since many Europeans live near the coasts. Storm surges can be activated as results of wind-driven waves and winter storms (Smith et al., 2000), whereas long-term processes are linked to global mean sea-level rise (Woodworth et al., 2005). Ensemble modelling for the Baltic and southern North Sea indicate fewer but more extreme surge events (Lowe and Gregory, 2005) may be particularly harmful to prone erosion and flooding in estuaries, deltas and embayments (Woth et al., 2005).

The Netherlands is an example of a country that is highly susceptible to both sea-level rise and coastal flooding because 55% of its territory, where 60% of its population lives and 65% of its Gross National Product (GNP) is produced below sea level. Expected sea-level rise is projected to have impacts on Europe's coastal areas including land loss, groundwater and soil salinisation and damage to built property and infrastructures (Devoy, 2007; Nicholls and de la Vega-Leinert, 2008).

Hinkel et al. (2010) found that the total monetary damage in coastal areas of Member Countries of the European Union (EU) caused by flooding, salinity intrusion, land erosion and migration is projected to rise strongly, but adaptation can reduce the number of people flooded by two orders of magnitude and the total damage costs by factors 4 to 5.

Gale winds

Windstorms hit particularly, but not exclusively, coastal areas of Europe. Severe windstorms are associated with westerly flow (80%) occurring mainly during moderately positive NAO phase (Donat et al., 2009). The most frequent track runs along the north coasts of the British Isles onto the Norwegian Sea, but they may take meridional pathways affecting the northern Iberian Peninsula, France and central Europe. In the most severe extra-tropical windstorm month, December 1999, when three events struck Europe (Anatol - December 3, Denmark; Lothar - December 26, France, Germany and Switzerland; and Martin - December 28, France, Spain, and Italy), insured damage was in excess of €9 billion (Schwierz et al., 2009). Immense economic losses were generated by gale winds via effects on electrical distribution systems, transportation, and communication lines, private, and damage on buildings vulnerable elements (eg. lightweight roofs) and by trees falling on houses. A substantial increase in wind damage is not predicted, as can be extracted from a lack of consensus on projected wind speed changes over Europe (Barthod, 2003; Nilsson et al., 2004; Schumacher and Bugmann, 2006).

Flooding

Flooding is the most frequent and widely distributed natural risk in Europe. Economic losses from flood disasters in Europe have increased considerably in last decades due to climatic and non-climatic factors (Lugeri et al., 2010). The latter include socio-economic development, urbanization and infrastructure construction on traditional flood-prone area. Enormous flood impacts were due to a few individual flood events (e.g. 1997 floods in Poland and Czech Republic, 2002 flood in central Europe, and 2007 summer floods in UK). Flash floods from extreme precipitation are enhanced on impervious (urbanized areas) and on catchments after occurrence of a forest fire, due to soil hydrophobia and water repellence of some organic components. Particularly vulnerable are new urban developments and tourist facilities, such as camping, recreation areas (e.g. a large flash flood in 1997 in the Spanish Pyrenees, conveying a large amount of water and debris to a camping site, resulted in 86 fatalities; cf. Benito et al. 1998). Apart from new developed urban areas, flood damage will likely increase in relation to linear infrastructures, such as roads, railroads, and underground rails with inadequate drainage (Defra, 2004a; Mayor of London, 2005).

Two independent model-based studies show (Kundzewicz et al., 2010) that over approximately 30% of the area of Europe, the mean recurrence interval corresponding to what used to be the 100-year flood in the control period, is projected to decrease to below 50 years in the end of the 21st century. Projections (cf. Figure 4-14, from Dankers and Feyen, 2008) indicate that over much of Poland, Germany, Austria, Switzerland, France, and Italy the floods corresponding to the return period of 100 years in the control period are expected to become considerably more frequent. However, over much of Russia and Scandinavia, with snowmelt being important flood generating mechanism, floods corresponding to 100-year return period in the control period may become less frequent in the future. Increase of frequency of short-duration precipitation in most of Europe is likely to lead to increased risk of destructive flash floods and urban floods (EEA, 2004b).

[INSERT FIGURE 4-14 HERE:
Figure 4-14: Recurrence interval (return period) of today's 100-year floods (i.e. flood with a recurrence interval of 100 years during the period 1961-1990) at the end of the 21st century (2071-2100), for emissions scenario SRES A2. Source: Dankers and Feyen (2008).]

In glaciated areas of Europe glacial lake outburst floods (GLOFs) are the most important natural hazard, likely to produce immense socio-economic and environmental impacts in the affected areas. The highest GLOF hazard is related to glacial lakes dammed by young, unstable and unconsolidated moraines, and lakes in contact to the active ice body of a glacier (Damen, 1992). Intense lake level and dam stability monitoring on most glacial lakes in Europe helps prevent future major breach catastrophes. In case of flooding, major impacts are expected on infrastructure and settlements even at long distances downstream from the hazard source area.

Landslides

Climate change can modify frequency of landslides (Schmidt and Dehn 2000), which can impact on settlements and linear infrastructures. Observed trends in landslide occurrence point out to a decrease in activity in most regions, particularly in southern Europe, where revegetation on scree slopes enhanced cohesion and slope stability (Corominas et al. 2005). Reactivation of large movements usually occurs in areas with a groundwater flow and areas of river erosion. Earth flows and landslides may develop after intense precipitation events, likely to be enhanced by climate change.

Snow

Snow avalanches are an ever-present hazard with the potential for loss of life, property damage, and disruption of transportation. Increased use of mountain areas for recreation and tourism leads to an increased rate of mortality due to snow avalanches. During the period 1985–2005, avalanche fatalities have averaged approximately 120 per year in the European Alps (McClung and Schaerer, 2006). Increased winter precipitation may result in more than average snow depth or the duration of snow cover contributing to avalance formation (Schneebeli et al., 1997). Climate change impact on snow cover also includes decrease in duration, depth and extent and a possible altitudinal shift of the snow/rain limit (Beniston et al., 2003) Therefore, predictions about future avalanche activities under climate change is highly uncertain, depending on regional characteristics A potential increase of snow avalanches in high altitudes has impact on human activities (loss of life and infrastructures), andfurther impacts on mountain forest (Bebi et al., 2009.). Europe is the leading region in skiing industry, and there is a considerable sectoral vulnerability to mild winters. The ski industry in central Europe is projected to be disrupted by significant reductions in natural snow cover, especially at lower elevations (Kundzewicz and Parry, 2001, Alcamo et al., 2007). Hantel et al. (2000) found that at the most sensitive elevation in the Austrian Alps (below 600 m in winter and 1400 m in spring) and with no snowmaking adaptation considered, a 1°C rise leads to four fewer weeks of skiing days in winter and six fewer weeks in spring. Beniston et al. (2003) projected that a 2°C warming with no precipitation change would reduce the seasonal snow cover at a Swiss Alpine site by 50 days/yr, and with a 50% increase in precipitation by 30 days/yr.

Adaptation

Adaptation potential of European countries is relatively high, because of high gross domestic product and stable growth, educated and stable population (with possibility to move across the region) and well developed political, institutional, and technological support systems (Kundzewicz and Parry, 2001). Adaptation to weather extremes allows curbing the exposure, the adverse impacts, and the vulnerability. A special European Union (EU) Solidarity Fund (Hochrainer et al., 2010) has been established to assist recovery after major natural disasters, and national and EU adaptation programmes are being implemented in several countries as well as in the (CEC, 2009). However, some groups of people – economically disadvantaged, elderly, living alone or having pre-existing disease, are particularly vulnerable. The natural ecosystems in Europe that are most vulnerable to climate change and climate extremes are located in the Arctic, in mountain regions, in coastal zones (especially the Baltic wetlands) and in various parts of the Mediterranean, where ecosystems are already affected by ongoing warming and decreasing precipitation (Alcamo et al., 2007).

Much work is being done in Europe to improve flood preparedness, including EU Floods Directive and activities of river basin commissions. Due to the large uncertainty of climate projections, it is currently not possible to devise a rigorous, scientifically-sound, procedure for redefining design floods (e.g. 100-year flood) under strong non-stationarity of the changing climate and land use. For the time being it is recommended to adjust design floods using a “climate change safety factor” approach (Kundzewicz et al., 2010).

Adaptation makes it possible to enhance beneficial effects of climate change (e.g. by introducing longer-cycle varieties where wetter conditions are expected in the future warmer climate in the North of Europe) as well as to reduce the negative effects (e.g. by advancing sowing time for crops grown in the Mediterranean basin), cf. Moriondo et al. (2010).

Promising adaptation options of forestry to gale winds in Europe were found (Schelhaas et al., 2009) to limit the increase in exposure and vulnerability, e.g. by increasing the harvest levels that curb the current build-up of growing stock and reduction of the share of old and vulnerable stands.

[INSERT TABLE 4-14 HERE
Table 4-14: Summary of climate extremes in Europe – hazard, exposure, vulnerability, and impacts

4.5.5. Latin America

Extreme droughts and the vulnerability of the Amazon forest

In the short span of 4 years, the Amazon basin experienced one of its most severe droughts in 2005 (Marengo et al. 2008a, Zheng et al. 2008) and a very large, record breaking discharge in 2009 (Climanalise, 2009). The 2005 drought was atypical because it affected mostly the western and southwestern Amazon, as opposed to the more typical El Niño-related droughts which affect central, northern and eastern Amazon, such as the severe drought in northern Amazon in early 2010 (Climanalise, 2010). It is uncertain what the ecological impacts of the droughts are since satellite-based analyses of productivity (Saleska et al, 2007; Huete et al., 2006) show increased productivity in the affected areas during droughts, while other study based on in in-situ forest inventories observed loss of productivity and increased tree mortality and carbon loss (Phillips et al., 2009) during droughts and subsequently. By and large, droughts in the Amazon are strongly linked to enormous increases in forest fires (Aragão et al., 2007, Cochrane and Laurance, 2008; Mlahi et al., 2008).

A number of studies (reviewed extensively in Nobre and Borma, 2009) attempted to determine quantitatively ‘tipping points’ for the Amazon forest in terms of climate change due to global warming or to deforestation. Current figures indicate that there could be a partial collapse of the Amazon forest (also termed ‘savannization’ because the new climate would be typical of tropical savannas) for global warming exceeding 3.5 to 4 C (Salazar et al., 2007, Betts et al., 2008) or for the total deforested area surpassing 40% of the total forest area (Sampaio et al., 2007). If the frequency of droughts in the Amazon increase, as projected by some studies (Cox et al., 2008; Marengo et al., 2009), coupled to increase of forest fires (Nepstad et al., 2004, Cardoso et al., 2008, Nepstad et al., 2008), the Amazon forest will become much more vulnerable (Nobre and Borma, 2009). Long-term rainfall-exclusion experiments for central (Nepstad et al., 2007 and Brando et al., 2008) and northeastern Amazon (Fischer et al., 2007) showed large tree mortality.

Extreme rainfall and natural disasters: Examples from Venezuela and Southern Brazil
Extreme rainfall episodes have caused natural disasters of great proportion in parts of Latin America, causing hundreds to thousands of fatalities in mud/land slides, where the disasters of December 1999 (Lyon, 2003) and February 2005 in Venezuela and the one in November 2008 in southern Brazil (Silva Dias et al., 2009) are typical illustrations of the serious impacts of such incidents. Projections of rainfall extremes for the future, although highly uncertain at present, point out for more intense rainfall episodes due to global warming (Marengo et al., 2009). Extreme rainfall anomalies over South America are linked to large-scale SST anomalies (Halylock et al. 2006). When the North Tropical Atlantic (NTA) and the Equatorial Pacific (Niño 3 region) anomalies are of opposite signs and the first one is positive while the second one is negative, the rainfall response is stronger in the northern coast of Venezuela as well as in the Pacific coast of Central America during the Nov-Feb period, which partly explains the extreme rainfall of those two episodes. In the future, that configuration in SSTs leading dry season rainfall extremes may hold and even increase for SRES A2 experiments for the middle part of the century (Guenni et al., 2010). So far, the response to those devastating episodes in Venezuela has been to develop an early warning system for rainfall and mudslide risk and a preparedness program for people exposed to risk (Wieczorek et al., 2001).

A generalized increase of rainfall over SE South America over the last 30 years, attributed mostly to the positive phase of the PDO and more frequent El Niño episodes, is well documented (Barros et al., 2008. Grim and Tedeschi, 2009, among many others). If that is the driving mechanism of rainfall increase, it may decrease in the present and future decades since the PDO may have changed phase (e.g., Vera and Silverstrini, 2008). However, that region has been simultaneously experienced warming and the increase of frequency of intense rainfall episodes (> 100 mm/48 hours) (Camiloni et al., 2005) in that broad region can be attributed in part to the warming (Marengo et al., 2008b). That kind of intense rainfall is projected to increase in the future (Marengo et al. 2009). In particular, the Itajaí-Açu river basin, in Santa Catarina, southern Brazil, is naturally very prone to devastating floods, normally associated to El Niño-related abundant rainfall (Silva Dias et al., 2009). In November 2008, that river valley experienced its most severe flood in recorded history, with 5-day rainfall records exceeding 500 mm along the basin, claiming over 130 lives, mostly due to mud slides in hills on the edge of the floodplain (Silva Dias et al., 2009).

The response to historical floods in the Itajaí-Açu valley illustrates how complex social mechanisms to seek adaptation to climate extremes can be. One response to the extensive 1983 floods in that valley was to implement a hydrological early warning system for the flood plain. To reduce exposition to risk, gradually inhabitants living in the floodplain moved to higher ground, particularly occupying steep forested hills on the edges of the floodplain, and deforesting them in the process of occupation. The majority of casualties in November 2008 were caused by mudslides on the those hills (Fundação BUNGE, 2009). In sum, to escape from one hazard (floods), the population became vulnerable to other risk (mudslides) (Silva Dias et al., 2009).

4.5.6. North America

[Pending]

4.5.7. Oceania

The region of Oceania consists of Australia and New Zealand and several Small Island States that are tackled in Section 4.5.10.

Introduction
Extreme events have severe impacts in both Australia and New Zealand. In Australia, weather-related events cause around 87% of economic damage due to natural disasters (storms, floods, cyclones, earthquakes, fires and landslides), cf. BTE (2001). In New Zealand, floods and droughts are the most costly climate disasters (Hennessy et al., 2007).

The climate of the 21st century in the Oceania region is virtually certain to be warmer, with changes in extreme events. Heat waves and fires, floods, landslides, droughts and storm surges are projected to increase in intensity and frequency. Rain events are likely to become more intense, leading to greater storm runoff, but with lower river levels between events. Risks to major infrastructure are likely to increase i.e. design criteria for extreme events - to be exceeded more frequently. Risks include failure of floodplain protection and urban drainage/sewerage, increased storm and fire damage, and more heat waves, causing more deaths and more blackouts. Economic damage from extreme weather is very likely to increase and provide major challenges for adaptation (Hennessy et al., 2007).

The El Niño-Southern Oscillation (ENSO) is a strong regional driver of climate variability. In Australia, El Niño brings warmer and drier conditions to eastern and south-western regions (Power et al., 1998). In New Zealand, El Niño brings drier conditions in the north-east and wetter conditions in the south-west (Gordon, 1986; Mullan, 1995). The converse occurs during La Niña, in both Australia and New Zealand.

Temperature extremes
Trends in the frequency and intensity of most extreme temperature are rising faster than the means (Alexander et al., 2007).

In Australia, from 1910 to 2004, the average maximum temperature rose 0.6°C and the minimum temperature rose 1.2°C (Nicholls and Collins, 2006). From 1957 to 2004, an increase in hot days (above 35°C) of 0.10 days/yr was observed in the Australian average, an increase in hot nights (above 20°C) of 0.18 nights/yr, a decrease in cold days (below 15°C) of 0.14 days/yr and a decrease in cold nights (below 5°C) of 0.15 nights/yr (Nicholls and Collins, 2006).

During the Eastern Australian heat wave, in February 2004, temperatures reached 48.5°C in western New South Wales. About two-thirds of continental Australia recorded maximum temperatures over 39°C. The Queensland ambulance service recorded a 53% increase in ambulance call-outs (Steffen et al., 2006).

An increase in heat-related deaths is projected in the warming region (Hennessy et al., 2007). Assuming no planned adaptation, the number of deaths is likely to rise from 1,115/yr at present in Adelaide, Melbourne, Perth, Sydney and Brisbane to 2,300 to 2,500/yr by 2020, and 4,300 to 6,300/yr by 2050, for all SRES scenarios, including demographic change (McMichael et al., 2003). In Auckland and Christchurch, a total of 14 heat-related deaths occur per year in people aged over 65, but this is likely to rise to 28, 51 and 88 deaths for warmings of 1, 2 and 3°C, respectively (McMichael et al., 2003). Ageing of the society is likely to amplify these figures. By 2100, the Australian annual death rate in people aged over 65 is estimated to increase from a 1999 baseline of 82 per 100,000 to 131-246 per 100,000, for the SRES B2 and A2 scenarios and the 450 ppm stabilisation scenario (Woodruff et al., 2005). Australian temperate cities are likely to experience higher heat-related deaths than tropical cities (McMichael et al., 2003).

Droughts
Droughts have become more severe because temperatures are higher for a given rainfall deficiency (Nicholls, 2004). In Australia, the damages due to droughts of 1982-1983, 1991-1995 and 2002-2003 were US$2.3 billion, US$3.8 billion and US$7.6 billion, respectively (Hennessy et al., 2007).

New Zealand has a high level of economic dependence on agriculture and drought in particular can cause significant disruption. The 1997-98 El Niño resulted in severe drought conditions across large areas of New Zealand with losses estimated at NZ$750 million (2006 values) or 0.9 per cent of GDP (OCDESC, 2007: 82). Drought conditions also have a serious impact on electricity production in New Zealand where 60 per cent of supply is from hydroelectricity and low precipitation periods result in increased use of fossil fuel for electricity generation, a mal-adaptation to climate change. Auckland, New Zealand's largest city suffered from significant water shortages in the early nineteen-nineties, but has since established a pipeline to the Waikato River to guarantee supply.

Droughts impact on water security in the Murray-Darling Basin in Australia, accounting for most of irrigated crops and pastures in the country. Annual streamflow in the Basin is likely to fall 10-25% by 2050 and 16-48% by 2100 (Hennessy et al., 2007).

Climate change is likely to change land use in southern Australia, with cropping becoming non-viable at the dry margins if rainfall is reduced substantially, even though yield increases from elevated CO_2 partly offset this effect (Sinclair et al., 2000; Luo et al., 2003).

Wildfire

Wildfires around Canberra in January 2003 caused US$261 million damage (Lavorel and Steffen, 2004), with about 500 houses destroyed, four people killed and hundreds injured. Three of the city's four dams were contaminated for several months by sediment-laden runoff (Hennessy et al., 2007).

An increase in fire danger in Australia is associated with a reduced interval between fires, increased fire intensity, a decrease in fire extinguishments and faster fire spread (Hennessy et al., 2007). In south-east Australia, the frequency of very high and extreme fire danger days is likely to rise 4-25% by 2020 and 15-70% by 2050 (Hennessy et al., 2006). By the 2080s, 10-50% more days with very high and extreme fire danger are likely in eastern areas of New Zealand, the Bay of Plenty, Wellington and Nelson regions (Pearce et al., 2005), with increases of up to 60% in some western areas. In both Australia and New Zealand, the fire season length is likely to be extended, with the window of opportunity for controlled burning shifting toward winter (Hennessy et al., 2007).

Intense precipitation and floods

From 1950 to 2005, extreme daily rainfall has increased in north-western and central Australia and over the western tablelands of New South Wales (NSW), but has decreased in the south-east, south-west and central east coast (Gallant et al., 2007).

Floods are New Zealand's most frequently experienced and expensive hazard (OCDESC, 2007) affecting both agricultural and urban areas. Being long and narrow New Zealand is characterised by small river catchments and accordingly shorter flood warning times.

Increase in precipitation intensity is likely to cause greater erosion of land surfaces, more landslides, and a decrease in the protection afforded by levees (Hennessy et al., 2007). Assuming the current levee configuration, the proportion of the Westport town (New Zealand) inundated by a 1-in-50 year event is currently 4.3%, but rises to 13 to 30% by 2030, and 30 to 80% by 2080 (Gray et al., 2005). Peak flow increases 4% by 2030 and 40% by 2080.

Storm surges

Over 80% of the Australian population lives in the coastal zone, with significant recent non-metropolitan population growth (Harvey and Caton, 2003). About 711,000 addresses (from the National Geo-coded Address File) are within 3 km of the coast and less than 6 m above sea level, with more than 60% located in Queensland and NSW (Chen and McAneney, 2006). These are potentially at risk from long-term sea-level rise and large storm surges (Hennessy et al., 2007). The area of Cairns at risk of inundation by a 1-in-100 year storm surge is likely to more than double by 2050 (McInnes et al., 2003).

Tropical cyclones

There is no trend in the frequency of tropical cyclones in the Australian region from 1981 to 2003, but there has been an increase in intense systems (very low central pressure) (Kuleshov, 2003; Hennessy, 2004).

Adaptation

Australia and New Zealand have a long history of flood management, though early attempts were mostly structural. Since the mid-twentieth century legislation has existed in New Zealand to enable a full range of responses including modifying the environment, modifying flood loss susceptibility and modifying the loss burden. Until the 1990s, however, most effort went into the former, as there were significant government subsidies for local catchment authorities to build stopbanks and other protective works. On the other hand non-structural measures tended to be over looked at the local planning level leading to intensive development in 'protected areas' and increased vulnerability to supra-design events (Ericksen, 1986). Economic restructuring in the second half of the 1980s resulted in the removal of subsidies, local government reform resulted in the merging of catchment management with other regional planning activities and the introduction of The Resource Management Act (1991) which had sustainable management as its cornerstone, and which replaced both catchment oriented and planning legislation, saw significant change towards a cooperative regime for hazard management (Dixen et al., 1997). Other hazard related legislation in New Zealand includes the Building Act 2004 and the Civil Defence Emergency management Act 2002. For agricultural disasters, particularly drought, farmers are eligible for Adverse Events recovery assistance administered by the Ministry of Agriculture Forestry and to social welfare services (Ministry of Social Development) where their income is severely reduced. Where farm it is considered that farms are unsustainable 'new start' grants are made available to assist farmers to leave the industry (Ministry of Agriculture and Forestry, 2010).

[INSERT TABLE 4-15 HERE:
Table 4-15. Climate extremes, vulnerability, and impact.]

4.5.8. Open Oceans

The ocean's huge mass in comparison to the atmosphere gives it a driving role in global heat budgets and chemical budgets. However, a very high level of uncertainty confounds predictions of extreme ocean events related to climatic changes (Keller et al., 2007). Possible extreme events are likely to be triggered by (1) warming of the surface ocean, with a major cascade of physical effects, (2) ocean acidification induced by increases in atmospheric carbon dioxide, and (3) reduction in oxygen concentration in the ocean due to a temperature-driven change in gas solubility and physical impacts from (1). All have potentially non-linear multiplicative impacts on biodiversity and ecosystem function, and each may increase the vulnerability of ocean systems, triggering an extreme event such as a mass extinction.

Surface warming of the oceans can itself directly impact biodiversity by slowing or preventing growth in temperature-sensitive species. One of the most well-known biological impacts of warming is coral bleaching, but ocean acidification also plays a role in lowering coral growth rates (Bongaerts et al., 2010). Direct impact of warming on other marine plants and animals, including the plankton, is likely to be important and will change how open ocean ecosystems operate, potentially favouring bacterial plankton over larger organisms (Legendre and Rivkin, 2008). Fish populations have been seen to be vulnerable to climate change both through direct impacts of temperature changes and acidity, and also via the altered ocean circulation (Johnson, 2010). These changes are likely to impact the overall catch potential in fisheries worldwide (Cheung et al., 2008).

A secondary impact of warming is the potential reduction in oxygen concentrations due to decline in the chemical capacity of seawater to retain dissolved oxygen at higher temperatures (Whitney et al., 2007). It has been predicted that deoxygenation will occur at 1 – 7% over the next century via this mechanism alone, continuing for 1000 years or more into the future (Keeling et al., 2010). An important impact may be an expansion of already existing oxygen minimum zones, especially in tropical oceans, which can kill animals at concentrations ranging from 40 to 200 µmol L^{-1} oxygen, depending on the species (see Figure 4-15; Vaquer-Sunyer and Duarte, 2008).

[INSERT FIGURE 4-15 HERE:
Figure 4-15: Median lethal oxygen concentration (μmol L^{-1}. Median lethal oxygen concentration (LC_{50}, in μmol L^{-1}) amoung four different taxa. The box runs from the lower (Q_1, 25%) to the upper (Q_3, 75%) quartile and also includes the median (*thick vertial line*). The range of data points not considered outliers is defined as 1.5 times the difference betweeen the quartiles (Q_3-Q_1), also known as interquartile range (IQR). The whiskers show the location of the lowest adn highest datum within this range, i.e., 1.5 * IQR. Shaded diamonds are outliers as per this definition. Redrawn after Vaquer-Sunyer & Duarte (2008). Copyright (2008) National Academy of Sciences, U.S.A.]

However, some of the greatest impacts of warming are likely to be generated by the changes in marine circulation induced by warming that could act to isolate surface waters from deep waters, a mechanism known as "stratification", which involves heat-induced layering of the surface ocean, inhibiting deep mixing. Among other impacts, this exacerbates the deoxygenation problem many-fold by preventing ventilation of deep waters to the surface, where they can re-oxygenate in contact with air. This then physically limits the re-oxygenation of the ocean interior (Keeling et al., 2010). In addition, almost all climate models predict an increase in evaporation in the tropics and increased precipitation in high latitudes, which would increase stratification by the input of low-density fresh water at the ocean surface (Orr et al., 2005).

This limitation of exchange seems to override the potentially positive impact on oxygen concentrations driven by a reduction in surface productivity in more permanently stratified waters (Keeling et al., 2010): A reduction in mixing reduces the regular delivery of deep nutrients to the surface of the ocean needed to fertilize light-driven photosynthesis by the plant plankton ("phytoplankton", that release oxygen). This reduction in nutrient supply has another cascade of impacts. Low nutrient conditions are likely to support species of phytoplankton with lower nutrient requirements that are of poorer nutritional value to their crustacean "zooplankton" predators, thus changing the structure and function of entire aquatic food webs (van de Waal et al., 2010). This sort of impact has been documented as a reduction in krill populations and an increase in jellies such as *salps* in the Southern Ocean (Atkinson et al., 2004).

Climate changes affect the temperature and salinity of ocean and global termohaline circulation, and also sea ice which influences communication between oceanic and atmospheric processes (Barber *et al.*, 2008). One of the most profound and potentially rapid changes in circulation predicted by climate models is the possible failure of the Meridional Overturning Circulation (MOC) in the North Atlantic. The MOC is the northward flow of water in the surface Atlantic Ocean which brings warm water from the tropics towards the Arctic. The water cools progressively as it moves north due to heat-loss to the atmosphere, eventually cooling to such a density that it sinks to the deep ocean and tracks southward again, along the sea floor. The MOC is one of the oceans' most important vertical mixing regions, where large amounts of surface gases (including CO_2), and plankton (in this context, stored carbon), are carried deep into the ocean interior. Once there, these materials are essentially stored for the period of a whole ocean overturn, that is, about 1000 years. Many models predict a weakening or collapse of the MOC in response to climate change, due both to surface warming and to an increase in freshwater influx from melting polar sea-ice (Keller et al., 2010). Enormous effort has gone into reducing uncertainties associated with these predictions because of the potentially catastrophic environmental and economic impact associated with an MOC failure (Brennan et al., 2008), since an MOC would radically alter current climate patterns. Some models predict a "fast feedback" involving increased cloud cover and significant surface cooling throughout Western Europe (Laurian et al., 2009). Changes in the MOC in geologic history were associated with large and abrupt climatic changes in the North Atlantic region, including collapse of plankton stocks and significant reductions in ocean production (Schmittner, 2005).

Finally, the dissolution of increasing concentrations of carbon dioxide into the ocean from the atmosphere perturbs the carbon-dioxide - carbonate equilibrium such that the ocean becomes more acidic and calcium concentrations are reduced. Calcification of marine organisms is one of the key processes likely to be disrupted by acidification, of central importance because of its involvement in the formation of hard structures (coral skeletons, invertebrate shells, carapaces of larval fish). The primary open-ocean impacts will occur initially in high latitude regions such as the Southern Ocean, where significant reductions in calcium availability are likely to occur by 2050 (Orr et al., 2005), but will move progressively into lower latitudes. This, in combination with warming, is likely to pose a major threat to coral reefs (Jury et al., 2010). But some of the major impacts may be seen primarily in high latitudes – especially vulnerable, for example, are shelled organisms called *pteropods*. These are important high latitude zooplankton feeding major fish groups including salmon and herring, as well as baleen whales, and also perform a carbon storage function, carrying embedded carbon from the surface to the deep ocean via sedimentation of their shells (Orr et al., 2005).

In concert, it is expected that the impact of several concurrent impacts (temperature, stratification, acidity) increases the probability for extreme events in the ocean.

Changes in open oceans are particularly strong in polar regions (cf. 4.5.9). Spectacular reduction of the total Arctic sea ice area, based on satellite data, has been detected (Serreze et al., 2007). The maximum value in the period 1979-2009 (7.88 million km^2) was observed in September (seasonal minimum) 1996, and the minimum (4.3 million km^2, i.e. nearly twice less) - in September 2007. In the period 1990-2005, the perennial ice thickness was reduced, on the average, by 110 cm throughout the Arctic basin, as compared with its average thickness of about 3 m (Nagurnyi, 2009).

[INSERT FIGURE 4-16 HERE:
Figure 4-16: Ice covered area (S) in Arctic in September (million square kilometers). Data from [NSIDC ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/Oct/N_9_area.txt.]

Ice cover does not allow navigation of the ships. Navigation in the Arctic Ocean is only possible during the time interval when northern coasts of Eurasia and North America do not have ice cover. During periods of low ice concentration, ships are navigated towards ice-free passages, away from multi-year ice (that has accumulated over several years). Regional warming provides favourable conditions for the sea transport going through the Northern Sea Route along the Eurasian coasts and through the Northwestern Passage in the north of Canada and along Alaska (Impact of Warming Arctic, 2004). In September 2007, when the Arctic Sea ice area was extremely low, ice disappeared almost completely in northern passages of the North America and Northwest Passage was opened up. In Russia, this enabled service of ports of the Arctic region and remote Northern regions (import of fuel, equipment, food, timber, and export f timber, oil, and gas). However, owing to deglaciation in Greenland, New Land and Northern Land, the number of icebergs is suggested to increase (Strategic Prediction, 2005; Materials to the Strategic Prediction, 2005; Assessment Report, 2008).

The seasonal sea ice cycle affects also biological habitats. Such species of Arctic mammals as: polar bears, seals, and walruses, depend on the sea ice for their habitat; hunting, feeding, and breeding on the ice. Declining sea ice is likely to decrease polar bear numbers (Stirling and Parkinson, 2006).

Marine fisheries productivity is affected by changes in ocean conditions resulting from climate change. Food web structure and species distribution change. Marine fish and invertebrates tend to shift their distributions toward higher latitudes and deeper waters in response to climate change. Relative abundance of species may also change as some habitats become less appropriate for them (Redistribution of Fish Catch by Climate Change, 2009). Climate change may lead to large-scale redistribution of global fish catch potential, with a 30–70 percent increase in high latitude regions, e.g. the North Atlantic, North Pacific and poleward (Redistribution of Fish Catch by Climate Change, 2009).

It is assessed that 30 percent of the phytoplankton increase between 2006 and 2007 was due to large new areas of open water exposed due to extensive melting of sea ice. The other 70 percent of the increase could be attributed to a longer growing season, which in some Arctic regions was extended in 2007 by as much as 100 days, compared to 2006. Whales, seals, marine birds, zooplankton, and other marine animals all depend either directly or indirectly on phytoplankton for food.

4.5.9. Polar Region

Introduction

The Polar region consists of the Arctic, around the North Pole and the Antarctic, around the South Pole. Climate change in the Polar region is noticeable. Slow climate changes in the Polar regions can lead to extreme impacts. The Arctic region consists of a vast north treeless permafrost territory (north of Europe, Asia and North America, and several islands (including Greenland).

In the last century, air temperature in the Arctic region has risen twice as fast as the global temperature. In the Arctic region, the warming first leads to changes in cryosphere. Observational data are limited, but precise measurements in boreholes indicate that permafrost temperatures in the Arctic rose markedly during the last 50 years (Romanovsky et al., 2002), with rapid warming in Alaska (Hinzman et al., 2005), Canada (Beilman et al 2001) and Siberia (Pavlov and Moskalenko, 2002, Sherstyukov, 2009) and seasonal thaw depth (permafrost degradation) was observed. Sea ice extent in the Arctic Ocean has shrunk, improving navigation in the Arctic Region (cf. 5.4.8). Among other changes observed are: increase of inter-annual variability and extremeness of climate parameters and earlier onset of springs (temperature zero crossover).

Population density in the Polar region is low, so that impacts of climate change, and extremes, are not equally noticeable everywhere. The territory of Russian Arctic is more populated than other Polar regions. On this territory, impacts of climate change are most noticeable and affect human activities.

The positive impact of climate change is the reduction in heating season almost throughout the Arctic region. Apart from its duration, an important index is the heat deficit (heating degree-days) which needs to be compensated to maintain comfort temperature (Sherstyukov, 2007).

Warming cryosphere

For several key Arctic systems, notably Arctic sea ice and the Greenland Ice Sheet, recently observed changes are happening at rates significantly faster than predicted in previous expert assessments, notably IPCC AR4. While this primarily reflects the current limits of scientific understanding of the Arctic it also raises questions about the range of climate impact predictions that guide mitigation and adaptation (Stroeve et al., 2007).

Analysis of extent of melt of the Greenland ice sheet using passive microwave satellite data has shown a dramatic increasing melt trend since 1979 which appeared to be interrupted only in 1992 by the eruption of Mt. Pinatubo. Extreme melt years were 1991, 1995, and again 2002 (Abdalati and Steffen, 2001).

Recent changes in the Greenland ice sheet have, however, been complex. The colder interior has thickened, most probably as a result of recently high precipitation rates, while the coastal zone has been thinning. There is a growing body of evidence for accelerating coastal thinning, a response to recent increases in summer melt, and acceleration of many coastal glaciers suggest that thinning is now dominating the mass balance of the entire ice sheet. Using satellite radar interferometry observations of Greenland, Rignot and Kanagaratnam (2006) detected widespread glacier acceleration below 66° north between 1996 and 2000, which rapidly expanded to 70° north in 2005. Accelerated ice discharge in the west and particularly in the east doubled the ice sheet mass deficit in the last decade from 90 to 220 cubic kilometers per year. As more glaciers accelerate farther north, the contribution of Greenland to sea-level rise will continue to increase.

Climate warming leads to permafrost degradation, the 40-80-cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost (Sherstyukov, 2009).

Warming and thawing of the frozen ground in the Arctic region results in considerable mobilisation of greenhouse gases (Anisimov, 2007). The end-products of decomposition of the ancient organic substance are CO_2 (in aerobic conditions) and CH_4 (in anaerobic conditions). According to existing estimations, only the top hundred-metre layer of a frozen ground of the Arctic region contains about 10 thousand Gt of carbon (Semiletov, 1995, 1995, Zimov et al., 1997). Emissions of CO_2 from frozen ground and methane from gas-hydrates, can lead to essential increase of greenhouse gas concentration in the atmosphere and increase of global climate changes (Shakhova et al., 2005).

As frozen ground thaws, many existing buildings, roads, pipelines, airports, and industrial facilities are destabilized. From 1990 to 1999 the number of buildings which had various sorts of damage has increased in comparison with previous decade by 42 % - 90 % in the north of Western Siberia (Anisimov and Belolutsky, 2002; Weller and Lange, 1999).

An apartment building collapsed following melting permafrost in the upper part of the Kolyma River Basin, and over 300 buildings were severely damaged in Yakutsk as a result of retreating permafrost. More than half of buildings in Pevek, Anderm, Magadan, and Vorkuta have also been damaged (Anisimov, Belolutskaya, 2002; Anisimov, Lavrov, 2004). Approximately 250 buildings in Norilsk industrial district had significant damage caused by deteriorating permafrost and approximately 40 apartment buildings have been torn down or slated for demolition (Grebenets, 2006).

Changes in permafrost damage the foundations of buildings and disrupt the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10-12% in 20-25 years, with permafrost borders moving 150-200 km northeast (Anisimov *et al.*, 2004).

In polar region, in the conditions of impassability, frozen rivers are often used as transport ways. In the conditions of climate warming, rivers freeze later and melt earlier than before. Duration of operation of transport ways to the Far North of Russia decreases with increase of air temperature in winter and spring (Mirvis, 1999). Work in tundra has become much more difficult given impediments of passing through the melted tundra.

Although seasonal snow cover on land is highly variable, it has important effects on the processes and local climate, primarily through its insulating properties and high albedo. In Eurasia, and to a lesser extent North America, there has been a persistent 5-6 day/decade increase in the duration of snow-free conditions over the past three decades (Dye, 2002). The reduction of snow residence time occurs primarily in spring. Projections from different climate models generally agree that these changes will continue. Likely impacts include increases in near-surface ground temperature, changes in the timing of spring melt-water pulses, and enhanced transportation and agricultural opportunities (Anisimov et al., 2005).

In the north of Eurasia, duration of snow cover has decreased in last decades (Shmakin, 2010) and accumulation of snow in spring is capable to thaw intensively and to cause flooding. The annual number of days with sharp warming has increased in the north of Eurasia. In such days there is a sharp thawing of snow (Shmakin, 2010).

The warming in the Arctic leads to a shift of vegetation zones, bringing wide-ranging impacts and changes in species diversity, range, and distribution. In Alaska, over the last 50 years the confines of the forest zone have shifted to the North by 10 km displacing tundra zone (Tape et al., 2006; Sturm et al., 2001). In the mountain regions of North Sweden forests have shifted upwards by 60 m over a hundred years (Truong, Palm, 2006). As warming in the Russian Arctic degrades permafrost, vast territories of tundra may be replaced by taiga.

Floods

From mid 1960s to the beginning of 1990s, winter runoff of the largest rivers of Siberia (Yenisei, Lena, Ob; the total runoff of these three rivers makes approximately 70 % of the global river runoff into the Arctic Ocean) has increased by 165 km^3, i.e. about annual production of ground waters on a shelf of Pacific sector of Arctic regions (Savelieva et al., 2004).

Changes in freshwater inflow to the system of Arctic Ocean - Northern Atlantic may affect the performance of the termohaline circulation. The processes occurring on the scale of the Arctic region, are capable to change the climate system at the planetary scale.

Rivers in Arctic Russia experience floods, but their frequency, stage and incidence are different in different parts of the Region, depending on flood formation conditions. Floods on the Sibierian rivers can be produced by a high wave of the spring flood and by rare rain or snow-rain flood, as well as by ice jams, hanging dams and combinations of factors.

Maximum river discharge was found to decrease from the mid-20th century to the early 1980s in to Western Siberia and the Far East, except for the Yenisei and the Lena rivers that exhibit positive trends. However, in the last three decades, maximum streamflow values began to increase over the most of the Arctic Russia (Semyonov and Korshunov, 2006), cf. Figure 4-17.

[INSERT FIGURE 4-17 HERE:
Figure 4-17: Annual change in the number of hazardous floods on rivers of Eastern Siberia, Western Siberia, and the Far East 1991-2006.

Snowmelt and rain floods on the rivers in the Russian Arctic continue to be the most frequent cause of hazardous floods (85% of all hazardous floods in the past 15 years). Hazardous floods produced by ice jams and wind tides make up 10% and 5% of the total number of hazardous floods, respectively. In the early 21st century, the probability of catastrophic wind tide-related floods (Pomeranets, 2005) and ice jam-related floods increased. The damage from floods depends not only on their level, but also on the duration of exposure. On average, a flood lasts 5-10 days, but sometimes high water marks are recorded to persist longer, e.g. for 20 days or more (Semyonov and Korshunov, 2006), in Altai, Transbaikalia and some areas of the Maritime Territory and Sakhalin with monsoon climate.

An increased number of damage-causing floods was recorded in Western Siberia, 86 (of which 31 in the Altai Territory and 14 in the Kemerovo Region), Eastern Siberia, 67 (28 in the Krasnoyarsk Territory and 16 in the Chita Region), and in the Northern area, 10 out of 17 floods occurred in the Arkhangelsk Region. (Assessment Report, 2008).

Droughts

Polar regions feature insecure agriculture and, among Polar regions, grain is produced mainly on the territory of Russia. Droughts have considerable and negative impact on the crop yield. In some regions of Siberia, climate became more arid, leading to the decrease in productivity of agriculture (Sirotenko et al., 2007). A decrease in productivity of ecosystems was noted in central and northeastern parts of European Russia, in the south of Eastern Siberia and in the Far East (Sirotenko, Abashina, 2008). Modelling of forest fires in Siberia shows that the warming may result in the increase of risk of severe forest fires.

Coastal erosion

Coastal erosion along a 40-mile stretch of Alaska's Beaufort Sea doubled between 2002 and 2007. It is linked to the declining sea ice extent, increasing summertime sea-surface temperature, rising sea level, and increases in storm power and corresponding wave action. The recent trends toward warming sea-surface temperatures and rising sea-level may act to weaken the permafrost-dominated coastline by helping more quickly thaw ice-rich coastal bluffs and may potentially explain the disproportionate increase in erosion along ice-rich coastal bluffs relative to ice-poor coastal bluffs. Any increases in already rapid rates of coastal retreat will have further ramifications on Arctic landscapes - including losses in freshwater and terrestrial wildlife habitats, in subsistence grounds for local communities, and in disappearing cultural sites, as well as adversely impacting coastal villages and towns. In addition, oil test wells are threatened (Jones et al., 2009).

Coastal erosion is a significant problem in the Arctic. The Arctic coastlines are highly variable and their dynamics are a function of environmental forcing (wind, waves, sea-level changes, sea-ice, etc.), geology, permafrost and other elements (Rachold et al., 2005). Under global warming scenarios, the risk of entire communities disappearing due to coastal erosion is greatly increased. The cost to move an entire village or town could devastate the local economy. Therefore, a better understanding of global warming effects and atmospheric forcing on the coast is essential.

Permafrost degradation along the coast of the Kara Sea may lead to intensified coastal erosion, which moves the coastline back by 2-4 meters per year (Anisimov, Lavrov, 2004). This coastline retreat poses considerable risks for coastal population centres in Yamal and Taymyr and on other littoral lowland areas.

Climate refugees may emerge if climate change significantly damages housing. There have already been climate refugees in Arctic territories of the United States (Shishmaref) and Canada (Tuktyaktuk). Coastal erosion has also become a problem for residents of Inupiat and on the island of Sarichev.

4.5.10. Small Island States

Introduction

Small island states, on the Pacific, Indian and Atlantic oceans, are regularly identified as being among the most vulnerable to climate change and climate-related natural disasters (e.g. Hyogo Declaration; Barbados Declaration, UNFCCC). In the light of current experience and model-based projections, small island states, with high vulnerability and low adaptive capacity, have legitimate concerns about their future (Mimura et al., 2007). Changes to climate means or variability may lead to extreme impact. Smallness renders island countries at risk of very high proportionate losses when impacted by disaster (Lewis, 1979; Pelling and Uitto, 2001).

Climate-driven sea-level rise could lead to a reduction in island size, particularly in the Pacific. Island infrastructure tends to predominate in coastal locations, e.g. in the Caribbean and Pacific islands, more than 50% of the population live within 1.5 km of the shore. Nearly all international airports, roads and capital cities in the small islands of the

Indian and Pacific Oceans and the Caribbean are sited along the coast, or on tiny coral islands. Sea-level rise will exacerbate inundation, erosion and other coastal hazards, threaten vital infrastructure, settlements and facilities, and thus compromise the socio-economic well-being of island communities and states. There is also strong evidence that under climate change, water resources in small island states, that are especially vulnerable to future changes and distribution of rainfall, will be seriously compromised. For example, many islands in the Caribbean are likely to experience increased water stress as a result of climate change (Mimura et al., 2007).

Since the early 1950s, by which time the quality of disaster monitoring and reporting improved in the Pacific Islands Region, there has been a general increasing trend in the number of disasters reported annually (Hay and Mimura, 2010).

Demography and Geography

Pacific Island Countries and Territories (PICTs) exhibit considerable demographic variety. The population of the region in 2009 stood at 9,677,000. This is dominated by Melanesia with almost 8.5 million people of which over 6.5 million lived in Papua New Guinea. At the other end of the scale there are some very small countries and territories with populations below 2,000 people (Tokelau and Niue). Population densities vary, but tend to be lowest in the most populous Melanesian countries, and highest in the small atolls. Population growth rates also vary but tend to be higher in Melanesia. The projected regional population for 2050 is 18.2 million (Source of data: SPC, 2009).

PICTs have a variety of characteristics rendering generalization difficult (see Table 4-16). There are four main types of island ranging from large inter-plate boundary islands formed by subduction and found in the south west Pacific Ocean which may be compared to the Oceanic (or intra-plate) islands which were, or are being, formed over ‘hot spots’ in the earth’s mantle. Oceanic islands range from volcanic high islands, some of which are still being formed and some of which are heavily eroded with step slopes and barrier reefs, to atolls which consist of coral built on submerging former volcanic high islands, through raised limestone islands, former atolls stranded above contemporary sea-levels. Each island type has specific characteristics in relation to disaster risk reduction. For example, atolls are particularly vulnerable to tropical cyclones, where storm surges can completely inundate them and there is no high ground to which people may escape. In contrast the inter-plate islands are characterized by large river systems and fertile flood plains in addition to deltas, both of which tend to be heavily populated. Fatalities in most of the worst climate related disasters in the region have been mostly from river flooding. Raised atolls are often saved from the storm surge effects of tropical cyclones, but during Cyclone Heta which struck Niue 2004, the 20m cliffs were unable to provide protection.

[INSERT TABLE 4-16 HERE:
Table 4-16: Pacific Island type and exposure to risks arising from climate change.]

Exposure

Drought is a hazard of considerable importance in PICTs. Atolls, in particular, have very limited water resources being dependent on their Ghyben-Herzberg fresh water lens, which floats above sea water in the pervious coral, and is replenished by convectional rainfall. High islands are characterized by orographic rainfall and a distinct wet (east) – dry (west) pattern emerges reflected in spatial differences in agriculture, with taro (wet) and yams (dry) epitomizing the divergence. During normal conditions the western Pacific tends to be wetter the central and eastern parts, though this trend is reversed during El Niño events which give rise to serious droughts in the western Pacific, including devastating frosts in the Papua New Guinea Highlands, the most densely populated region in the country, dependent upon sweet potatoes. During drought events, water shortages become acute on atolls in particular, resulting in stringent rationing in some cases and the use of emergency desalinization units in the most extreme cases. In the most pressing circumstances, communities drink coconut water at the cost of copra production.

While the focus of this report is on climatic extremes and sea-level rise and variability, geological disasters must also be considered in a review of disaster risk reduction in PICTs. Many of the islands located along the plate boundaries in the western part of the region are exposed to very high levels of seismological activity and there are several active volcanoes. Tsunami is a risk to all PICTs, but for those near to seismologically active areas, tsunamis pose a greater threat given the short warning time available. The magnitude of tsunami events may be increased by sea level rise and by coral reef degradation linked to warming temperatures

Changing vulnerabilities

Communities in PICTs traditionally had a range of measures that helped them to cope with the suite of disasters in the region (Campbell, 1985; 1990; 2006). While some of these measures may have been purposeful adjustments to a hazardous environment it is likely that many were incidental. Food security was sustained by producing surpluses which were dry stored (especially yams), fermented (especially taro and breadfruit), baked and dried. Diverse agro-ecosystems and garden fragmentation reduced overall vulnerability to extremes and famine foods were regularly eaten when shortages occurred. In many parts of the region dwellings were built with hipped roofs, strongly lashed posts and limited spaces for air to enter during high wind events. The *fale* and *bure* of Samoa, Tonga and Fiji were particularly wind resistant. In Fiji, traditional houses are built on a mound known as a *yavu* some being several metres high, depending on the status of the household. While not a purposeful disaster reduction measure, *yavu* helped protect houses from river and coastal flooding. Traditionally, many high island communities lived inland on fortified ridges, for example, but were encouraged to move to the coast to facilitate colonial and missionary objectives, and increasing exposure to storm surges. The region was covered by a complex patchwork of traditional exchange networks prior to colonization. Many of these networks were held together by traditional political and cultural practices and were maintained by the exchange of surplus production.

With the advent of colonialism these measures began to decline. A new religion, for example, undermined the rationale for some of the exchange networks and the cash economy enabled communities to purchase food rather than store it. The main commercial crop, coconuts for copra production, took land away from food crop production and introduced a vulnerable component to the cash economy: coconut palms, while resilient to high winds, often lose their fruit which can take up to seven years to regenerate (a long period without commercial income). With the expansion of commercial agriculture, subsistence farming has been constrained and in many areas soil fertility has declined and tapioca has become the dominant crop replacing the more nutritious and wind resistant taro and yam staples. Surplus food production is now uncommon in the region. Ironically, tapioca was introduced to many PICTs as post-disaster rehabilitation planting material.

Disaster relief began in the colonial period but tended to be ad hoc. Nevertheless, it contributed to the neglect of many of the traditional measures. Food preservation declined as has use of famine foods. With the advent of independence, relief became more important. Newly independent governments faced with disasters increased the provision of relief and became increasingly dependent upon externally derived assistance. Over the past decade the scale and scope of relief operations have increased significantly with coordination by UNOCHA and UNDP, the involvement of a large number of NGO humanitarian organizations and internet appeals launched within hours of the major events' occurrence. While contemporary Pacific Island communities have lost many of their traditional coping mechanisms and have become increasingly reliant on relief they still show a remarkable degree of resilience in the face of disaster.

Urbanization, the rate of which has increased rapidly in the past two decades (Connell and Lea, 2002), is also changing the nature of vulnerability in many PICTs. As urban populations grow so do the size of the squatter settlements which are often characterized by houses that are highly vulnerable to wind damage and are often located in flood (river and coastal) prone low-lying areas or on steep and unstable slopes. Urban planning is poorly developed in much of the region and where it is practiced often natural hazards are not a key consideration. At the same time most current disaster risk management in PICTs has a rural focus and while some coping mechanisms remain in rural areas, they are less likely to be maintained in the towns. Climate change induced migration is likely to cause further increases in urban populations exacerbating urban disaster vulnerability.

Impacts

The main impacts from climatic extremes in PICTS are damage to structures, infrastructure and crops during tropical cyclones and crop damage and water supply shortages during drought events. On atolls, salinisation of the freshwater lens and garden areas is a serious problem following storm surges, high wave events and 'king' tides. In the 2000s there were 56 disaster events listed in the ReliefWeb (2010) disaster history records. However, because five of these events affected more than one country there are 69 disasters listed for the period at the national level. Of the 56 events 35 were climate related (although four of the remainder were landslides which may have been triggered by heavy rains or by seismic activity). Two of the remaining 17 geological were tsunamis the effects of which may be increased by sea level rise and coral degradation. While the data are variable, and sometimes approximate, the death toll in the region in the same period of time was around 566 people of which 324 (57 per cent) were in climate related events. These events affected at least 690,000 people (97 per cent) and 66,000 were displaced (56 per cent). The availability of data, especially for smaller events, falls away prior to 2000, although in the previous decade 14 major climate related events resulted in 96 fatalities although during this period there was a severe and widespread drought associated with the 1997-98 El Niño event although there are no data on any fatalities.

Disaster Management

As noted earlier, most disaster management in the colonial era tended to be ad hoc and reactive. Fiji, was the first independent country to establish a programme, known as the Prime Minister's Hurricane Relief Committee which operated through to the 1980s by the Pacific Island Development Programme. At the regional level, the Pacific Disaster Preparedness Project was established in the early 1980s and it produced manuals, conducted workshops and carried out demonstration project (e.g. on building a hurricane resistant house). The next significant step was the establishment of the UNOCHA South Pacific Programme Office (SPPO) which instigated a number of activities including training of disaster management personnel throughout the region and provision of assistance for the establishment of national disaster management offices (NDMOs). The activities of the SPPO were later taken over by SOPAC which is now the home for regional disaster risk reduction activities. It is noteworthy that CCA falls under the mandate of SREP. As a result of the various regional activities most PICTs have NDMOs and a well trained cadre of disaster management officers. However, DRR still remains marginalized among the government activities of most countries and most disaster response remains in the management of relief and recovery operations. Since 2008, SOPAC has sought to have DRR better integrated into government activities by engaging with top level economic planners in the region.

Major investments in disaster preparedness and response in recent decades in the Pacific small island states have resulted in a decline in the number of fatalities per disaster. However, population growth and relocation, often into risk areas, have contributed to an overall trend of more people being affected by disasters. Encouragingly, economic losses per disaster have also been consistently low in recent decades (Hay and Mimura, 2010).

4.5.11. The Overall Links between Regions and Hazard Impacts

[Pending - Not sure if this is necessary]

4.5.12. Comment on 4°C Rise

Global warming at the level of 4°C is projected to render regional distribution of impacts negative for most regions. It should be stressed that the global warming of 4°C does not leads to a uniform warming – a much higher warming would take place in the Arctic. Regions specially affected by climate change are (IPCC Working Group II, 2007):

- The Arctic, because of high rates of projected warming on natural systems
- Africa, especially the sub-Saharan region, because of current low adaptive capacity as well as climate change
- Small islands, due to high exposure of population and infrastructure to risk of sea-level rise and increased storm surge
- Asian megadeltas, such as the Ganges-Brahmaputra and the Zhujiang, due to large populations and high exposure to sea level rise, storm surge and river flooding.

A 4°C warming would substantially aggravate negative impacts in the regions specified above, and produce negative impacts for most other regions.

4.6. Total Cost of Climate Extremes and Disasters

4.6.1. Introduction and Conception

The following subsection focuses on the economic impacts of weather extremes and disasters on humans, societies and ecosystems. These comprise of observed and projected future economic impacts, including economic losses and expected losses. Findings come from assessing the related literature as well as on evidence from former chapters (e.g., Chapter 3) and earlier subsections in this chapter.

To keep an integrated framework with the following chapters that mainly focus on risk management and adaptation issues, a conceptual introduction with key definitions covering both disaster risk management (DRM) and climate change adaptation (CCA) is given first. The typology of extremes, regions and sectors is based on the above contents. It is noticed that there are differences in economic impact and adaptation costs for developed and developing countries. Section 4.6.2 discusses methodologies for evaluating the costs of disasters, risks and adaptation. Section 4.6.3 explores the observed economic loss of particular extremes at the regional and global level with evidence from some key economic sectors. Section 4.6.4 discusses an aggregate estimate of global loss of a 4°C rise.

Key messages

Although the attribution of the increasing number and cost of weather disasters to climate change is still inconclusive, some general empirical trends of the economic impacts of weather disasters have been found; the absolute direct physical and economic losses from weather disasters have been increasing, together with per capita asset values. Indirect and secondary impacts are increasingly recognised but still not fully recorded. It should be noted that there are different scales of economic impacts of extremes among regions, sectors and social classes. It is likely that there is a negative correlation between proneness to disasters and stage of development, which is partly a cause and effect of the capacity gap between developed and developing countries.

There is much evidence that population growth and socio-economic structural shifts are the most important factors behind increasing losses from weather related extremes, especially in developing countries. This implies an imperative to incorporate reduction of economic impacts in long-term adaptation and development planning.

Disaster impacts can be devastating, particularly in heavily exposed low- and middle-income countries, and especially to the vulnerable within those countries. Because of the adaptation deficit in developing countries, they face increasing exposure to both population and assets risks during the process of urbanization and economic development, without full capacity to address social and economic vulnerability. For those more resilient rich countries, economic assessment is also very important to protecting their accumulated capital assets.

4.6.1.1. Conceptual Framework: Key Definitions

As mentioned in former chapters, extremes should be treated as physical events, and it is the economic and social impacts resulting from weather or climate events that become a disaster. Disasters are defined as extreme impacts associated with a severe disruption of the normal, routine functioning of the affected society, but disaster may also arise from a concatenation of physical, ecological and social responses to lesser physical events.

Cost of climate extremes and disasters: the net losses and benefits (in terms of avoided and reduced losses) of a specific extreme or disaster, including both disaster loss and cost of disaster management and adaptation.

Economic loss/damage cost of climate extremes: the net economic impact of extremes and disasters on human, society and ecosystems. This can be an observed or modelled impact. The damage cost or economic loss of extremes and disasters can be identified by impacts with the following classification: direct and indirect loss, tangible and intangible loss, market and non-market loss, etc. The distinction between direct and indirect is important, as most impact estimates available cover direct losses only, for instance insurance industry estimates. Indirect losses are however equally important, as they encompass in many cases a large share of overall losses, and also indicate the longer term economic impact of disasters. [References forthcoming]

Direct impacts are those caused by direct effects or the first-order consequences that occur immediately after a disaster-inducing event, usually inside the affected area. In some cases, direct losses have accepted market values that can be observed, such as the cost of destroyed buildings, roads and crops; direct impacts are generally a change in stock. Some approaches define impacts such as business interruption, or changes in the flow of goods and services as direct impacts as well. Here we see that while direct impacts may be comparatively easy to measure, accounting methodologies are not standardized and assessments are often incomplete. It is essential that the approach taken in any loss assessment is absolutely clear on its treatment of loss to avoid issues relating to, for example, double counting of stock and flow loss. [References forthcoming]

Indirect impacts include secondary and induced impacts that occur later in time in the affected location, as well as outside the directly affected location. They are caused by indirect and secondary effects which emerge later, including those that may be more difficult to attribute to the disaster event. These include both negative and positive factors, such as mental illness or bereavement resulting from disaster shock, and rehabilitation, health costs, reconstruction and disaster proof investment, including new employment in a disaster-hit area (disaster recovery booming). As the second-order consequences of disaster, indirect losses can be estimated by multiplier effects on for example, employment or investment for an economy. [References forthcoming]

Tangible and intangible impacts: Both direct and indirect impacts include tangible and intangible losses. Tangible losses are those that can be valued in the market place because they represent monetary production-based assets with monetary values, such as houses, vehicles, crops, facilities and so on, as well as loss of business income. Intangible losses do not have observable values in the market place and must be estimated using valuation techniques. Intangible damage comprises loss of life/morbidity (usually estimated using value of statistical life benchmarks), air and water pollution, ecosystem services, environmental amenity, and migration. Ecosystem services are functions performed by natural ecosystems that benefit humans such as carbon sequestration, air and water purification, sources of new medicines etc. [References forthcoming]

Direct impacts are not always the most significant outcome of disaster, in fact indirect impacts and unvalued intangible loss could far outweigh direct impacts. However, due to data availability and methodology, in many cases, mainly direct losses and tangible losses are covered in the estimates (Albala-Bertrand, 1993; Tol, 1994; Masozera et al, 2007; Schmidt et al, 2009; Hall et al, 2003; Huigen and Jens, 2006).

Probabilistic loss (Risk): Disaster risk is defined as “the potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.”(UNISDR, 2009a*)*. Risk is generally measured by a probability distribution of impacts and can be summarized by risk metrics such as the expected value and variance. Expected loss is defined as the aggregation of large and small possible loss events multiplied by their probability, mathematically the integral under a loss-probability curve. For extremes, which exhibit “fat tails”, i.e. the expectation alone is usually not a good metric to use, and using other metrics such as the variance is helpful. Although uncertainty issues and methodological gaps relating to risk assessment remain, there are some estimates of the historic and future global losses from weather extremes.

Adaptation cost: the cost of planning, preparing for, facilitating, and implementing adaptation measures including transition costs. (IPCC, 2001),, or cost for the actions on coping (Emergency/Disaster Response), recovering (Rehabilitation/Reconstruction), and anticipating/preparing (Preparedness, Warning Systems, Risk Retention and Transfer) (see Section 2.6).

Adaptation deficit: Identified as the gap between current and optimal levels of adaptation to climate change events or extremes (Burton and May, 2004).

4.6.1.2. Framework to Identify the Economic Impacts of Climate Extremes and Disasters

It has been argued widely that the mutual goals of DRM and CCA should be integrated in theory and practice because of intrinsic inter-linkages and their dynamic relationship (Burton and Van Aalst, 2004; Bouwer et al., 2007). While this is important, it is also important to note that they are different in a number of respects. DRM has traditionally focused on responding to and coping with disasters, and reducing damages. The total damage cost can be separated into avoidable and residual damage costs. The residual damage cost is the cost that would be not avoided even with a very high adaptation investment. The avoidable damage cost can be taken as the gross benefit of risk management, which may be feasible but not economically efficient (Parry et al., 2009; Pearce et al, 1996; Tol, 2001). Adaptation can be addressed within an iterative risk management framework, representing actions that have the effect of reducing exposure and vulnerability under anticipated climate change, as emphasized in the IPCC's Fourth Assessment Report (IPCC 2007) (see Chapter 1), and compared to estimated damage costs to be avoided.

CCA typically takes a longer term and dynamic perspective, compared to DRM, the latter assuming stationarity in the occurrence of weather hazards. DRM initiatives that emphasize, for example, increasing community resilience via income diversification, have benefits for disaster adaptation, but would also have wider benefits to the community that may contribute to CCA due to increased economic activity and wealth. As some studies have suggested, it is necessary to build connections between disaster protection investment and socio-economic development to reduce risk (Changnon, et al.; Rose, 2007).

It is not easy to avoid the "poverty trap" for many developing countries with inadequate stock of built, natural, social and human capital. Unless properly integrated and targeted, poverty reduction policies and goals will in themselves not address the specific climate change related risks for the most vulnerable people in developing countries. As stated by Adger et al (2001, pg193.) "the competing objectives of sustainable development are both highlighted and exacerbated by the dilemmas of climate change". Hence it is imperative to peruse integrated development, CCA and DRM initiatives that allow for co-benefits that build resilience and promote sustainable development. This requires theoretical and practical integration between the fields of DRM, CCA and development because of their intrinsic interconnectedness and complex feedback relationships.

4.6.1.3. Differing Economic Impacts in Developed and Developing Countries: The Empirical Evidence

The economic causes and repercussions of disasters have been well understood since Sen's (1981) seminal work on the social phenomena of drought and famine. For example, Bension and Clay (2004) have taken drought as a phenomenon of economic significance, with results such as sharp reduction in agricultural production, decline in rural income, reduced exports and employment, as well potential multiplier effects on the monetary economy. Also, the relationship between macroeconomic and climatic disasters has been explored with statistical and comparable analysis in recent years (Tol and Leek, 1999; Burton, et al, 1993; Albala-Bertrand, 1999; Kahn, 2005; Benson and Clay, 1998, 2003; Kellenberg and Mobarak, 2008; Rasmussen, 2004; Toya and Skidmore, 2007; Raschky, 2008; Lester, 2008; Noy, 2009).

Key determinants of economic impacts. The scale and magnitude of the economic impacts of natural disasters are determined by some key factors (OAS, 1991; Mechler, 2004; Gurenko, 2004, Cummins and Mahul, 2008; Benson and Clay, 2004): (i) natural hazard exposure: (ii) economic vulnerability – structure of economy, GDP, tax revenue, domestic savings and mature of financial markets, access to external finance, etc; (iii) geographical areas; (iv) technical and scientific development, (v) concentration of economic activity centres (e.g. large urban agglomerations) exposed to natural hazards.

The concentration of risk generally has a geographical focus (Swiss Re, 2008), and in particular developing countries are more vulnerable to climate change than developed countries. This is mainly because: (i) developing countries have less resilient economies since they depend more on natural capital and climate-sensitive activities (cropping, fishing, etc) (IPCC, 2007); (ii) they are often poorly prepared to deal with the climate variability and natural hazards they already face today (World Bank 2000); (iii) more damages are caused by mal-adaptation due to the absence of financing, information, techniques in risk management and week governance systems (Benson and Clay, 1998); (iv) there is less consideration of climate proof investment in regions with a fast growing population and asset stock (such as in coastal areas) (OECD, 2008; IPCC, 2001b). In particular, the adaptation deficit resulting from the level of economic development is considered as an important issue contributing to the gap between developed and developing countries (World Bank, 2007).

Macroeconomic and developmental impacts. It has been conceived that natural disasters may have some economic impacts on the pace and nature of development (Benson and Clay, 1998, 2003; Kellenberg and Mobarak, 2008;). Key adverse macroeconomic impacts experienced include reduced direct and indirect tax revenue, dampened investment and reduced long term economic growth through the negative effect on a country's credit rating and an increase in interest rates for external borrowing. With GDP and loss of life as major indicators of disaster impact, a growing literature has emerged that identifies important adverse macroeconomic and developmental impacts of natural disasters (Cochran 1994; Otero and Marti, 1995; Benson, 1997a,b,c; Benson and Clay, 1998, 2000, 2001, 2004; ECLAC 1982, 1985, 1988, 1999, 2002; Murlidharan and Shah, 2001; Crowards, 2000; Charveriat, 2000; Mechler, 2004; Hochrainer, 2006).

In general, the relationship between development and disaster impacts means a wealthy or richer country relates to a safer country, since a higher income level, governance capacity, higher education rate, climate proof investment and insurance system reduce the damage costs of disasters (Wildavsky, 1988; Rasmussen, 2004; Tol and Leek, 1999; Burton, et al, 1993; Albala-Bertrand, 1999; Toya and Skidmore, 2007; Raschky ,2008; Brooks, Adger, Kelly, 2005; Kahn, 2005; Lester, 2008; Noy, 2009). In some cases an inverted 'U' shape curve of the total impact over GDP per capita has been identified (Lester, 2008; Kellenberg and Mobarak,2008)**.** This implies that the countries most at risk of disaster will tend to be middle-income economies, since least developed countries tend to have simpler economic structures (Benson and Clay,1998). However, it may also indicate that middle-income countries invest relatively less in disaster prevention than high-income countries (Kellenberg and Mobarak, 2008).

There is an emerging consensus that, on average, natural disasters have a negative impact on short term economic growth (Cavallo and Noy, 2009; Raddatz, 2007; Noy, 2009). With a few exceptions, which consider disasters rather a problem of, but not for development (Albala-Bertrand, 1993, 2006; Caselli and Malhotra, 2004; Skidmore and Toya, 2002).

In the long run, despite inconclusive evidence, some researchers argue that poorer developing countries and smaller economies are likely to suffer more from future disasters than developed countries, especially in relation to large disasters (Raddatz, 2009; Hallegatte et al, 2007; Hallegatte and Dumas, 2009; Heger et al, 2008; Loayza et al, 2009). While the countries with highest income account for more of total economic and insured losses of disasters (Swiss Re, 2010), a greater portion of GDP and a higher fatality are seen in developing countries, which imposes a higher burden on governments and individuals in those poor countries. For example, during the 25 year period from 1979 to 2004 over 95% of natural disaster deaths occurred in developing countries and direct economic losses averaged US$54 billion per annum. (Mechler, 2010; Freeman, 2000; World Bank, 2001; Cavallo and Noy, 2009).

Some emerging developing countries, such as China, India and Thailand will likely face increased future exposure to extremes especially in highly urbanised areas, as a result of the rapid urbanization and economic growth (OECD, 2008; Bouwer et al., 2007). As one important case in point, in Fiji, natural disasters have resulted in reduced national GDP as well as decreased human development conditions as captured by the human development index (see Lal et al., 2009). In a case of Mexico, natural disasters saw HDI regressing by approximately two years development with increasing poverty levels (Rodriguez-Oreggia et al, 2009).

Also, in more developed economies important yet less pronounced effects have been detected. For example, in some cases a "creative destruction" was found, but only occurs in countries with high income level due to knowledge spillovers and new technology introduction (Cuaresma et al, 2008). However, the fiscal and trade deficits could deteriorate in the aftermath of climatic events both in developing and developed countries (Hegar et al, 2008; Mechler et al.2010). Mechler et al (2010) found that disasters pose significant contingent liabilities for governments (further discussed in 6.3) and prudent planning is necessary to avoid debilitating consequences as shown by the Austrian political and fiscal crisis in the aftermath of large scale flooding leading to losses of 3 billion Euro in 2002.

Costs and impacts not only vary among developing and developed countries, but between and within countries, regions and local areas due to heterogeneity of vulnerability and resilience. Some individuals, sectors, and systems would be less affected, or may even benefit, while other individuals, sectors, and systems may suffer significant losses in a same disaster. For example, women and children are found more vulnerable to disasters with lager disasters having an especially unequal effect (Neumayer and Plumper, 2007).

4.6.2. Methodology and Literature for Evaluating Disaster and Adaptation Costs and Impacts

DRM decisions are made under resource scarcity, and as such the cost effectiveness of adaptation and mitigation initiatives needs to be established. The mainstay for this analysis is credible estimates of the monetary value of the impacts of disasters and adaptation or mitigation efforts.

There are two major approaches for the economic valuation for the impacts caused by extremes and disasters at the regional and global level: a top-down approach and a bottom-up approach. The top-down approach is grounded in macroeconomics and often utilises general equilibrium modelling with regional or global statistic data. A bottom-up approach, derived from microeconomics, scales up data from sectors at the regional or local level to aggregate an assessment of disaster costs and impacts (see Van der Veen, 2004). Distinction can also be made between the DRM community and the CCA community, the former traditionally relying on bottom up approaches using catastrophe loss modelling (CLM, similar to the insurance industry); and the latter typically using integrated assessment models (IAMs) and economic models (a.o. CGE).

How disaster impacts are evaluated depends on numerous factors, such as the types of impacts being evaluated, the objective of the evaluation, the information and data available, and the spatial and temporal scale under consideration. It is important to note that macroeconomic approaches such as general equilibrium models look only at market dynamics and as such do not capture intangibles such as impacts on ecosystems.

While both macro- and microeconomic approaches to disaster loss assessment tend to delineate between direct and indirect costs, these are generally defined somewhat differently (Van der Veen, 2004). As discussed above, it is essential that policy-makers and practitioners are aware of these definitions of disaster impacts, and are consistent in their approach.

Welfare economics and disaster impact assessment. The bottom-up approach to disaster impact assessment attempts to evaluate the impact of an actual or potential disaster on consumer surplus. This approach values direct loss of or damage to property, as well as that of the interruption to the economy, impacts on health and wellbeing, on environmental amenity and ecosystem services. In short, it attempts to value the impact of the disaster to society. These approaches are rooted in a cost-benefit analysis framework (Van der Veen, 2004).

The first step in disaster impact assessment of this kind is to establish the spatial and temporal scale of the analysis. This is essential to economy-wide analysis to ensure the credibility of the estimate. For example, if a business in a disaster affected area experiences loss in infrastructure and potential trade, this may intuitively be considered a loss. However, if competing business within the analysis area picks up that trade instead, the net loss to the area is zero. Similarly, if a business that could not trade during the immediate aftermath of the disaster is able to recoup lost business at a later time – that is still within the temporal frame of the analysis – then this is not a loss (Handmer *et al*, 2002). Because disaster loss assessment attempts to evaluate the total, net impact of the disaster it is essential that any positive impacts, such as post-disaster boom spending are accounted for in the analysis.

Analysts must be clear and consistent in their treatment of costing property and infrastructure loss. While methodologies based on insurance practice sometimes use replacement value for costing damage, it may be more appropriate to use depreciated values, with the focus on the actual market value of the damaged asset (Handmer *et al*, 2002).

It may be that the largest impacts of disasters are the intangible losses such as ecosystem services, anxiety, heritage etc. These impacts are considered intangible because there is no direct market for them, and as such their values cannot be directly observed in the market place. There is however a body of work dedicated to attaching a monetary value to intangibles so that they may be included in impact assessments and cost-benefit analysis (TEEB, 2009, Pagiola *et al*, 2004).

The impact of increased air and water pollution, for example, can be estimated by looking at the cost of health care induced by this pollution increase. The ‘Travel Cost’ method estimates environmental amenity by looking at what people are willing to pay to visit an ecosystem. Similarly, hedonic pricing methods model the value of environmental amenity, scenic beauty or cultural values associated with environmental features. Stated preference methods such as contingent valuation use surveys to estimate the value people place on environmental intangibles (Pagiola et al. 2004). While there remains criticism of the use of contingent valuation, if carried out properly it can be a very useful tool (see Carson *et al*, 2003).

Unfortunately the cost of obtaining credible estimates for the value of intangibles is often prohibitive. In these instances benefit transfer techniques are available, where the values obtained from one study of a particular environment can be used in another evaluation. Benefit transfer is useful because it is cost effective, however practitioners must ensure the transfer is appropriate (Ready and Navrud, 2006).

Modeling disaster impacts and risks. Modeling disaster impacts generally involves generating an estimate in terms of risk, i.e. using probability based metrics. There is a substantial, yet very heterogeneous body of modeling research on the economic impacts by the DRM community. Most studies have focused on impact assessment remodeling actual events in the past and aiming at gauging to estimate the different, often hidden follow on impacts of disasters (e.g. Yezer and Rubin, 1987; Ellson et al., 1984; West and Lenze, 1994; Brookshire et al., 1997; Chang et al., 1997; Guimaraes et al., 1993; Rose 2007; Okuyama, 2008; Hallegatte et al., 2007). Existing approaches utilize a plethora of models such as Input-Output, CGE, economic growth frameworks and simultaneous-equation econometric models. Only a few models have aimed at representing extremes in a risk-based framework in order to assess the potential impacts of events if certain small or large disasters should occur (Freeman et al., 2002a; Mechler, 2004; Hochrainer, 2006; Hallegatte and Ghil, 2007; Hallegatte, 2008).

Analyses considering climate change in economic impact and risk modelling have only emerged over the last few years, and, as reported in 2007 by Solomon et al. much of the literature remains focussed on gradual changes such as sea-level rise and agricultural effects. Further, based on work by Nordhaus and Boyer (2000), extreme event risks in adaptation studies and modeling have usually been represented in a rather ad hoc manner, using add-on damage functions that are based on averages of past impacts and contingent on gradual temperature increase.

In most impact and modeling studies on extreme event risks, the focus has generally been on tangibles such as impacts on produced capital and the economy. Intangibles such as loss of life and impacts on the natural environment are generally not considered using monetary metrics (see Parry et al., 2009). Loss of life due to natural disasters, including future changes, however is accounted for in some studies (e.g. Jonkman, 2007; Jonkman et al., 2008; Maaskant et al., 2009). As also reported by Parry et al. (2009) when accounting for both tangible and intangible real impacts, and thus the adaptation costs, these are likely to be much larger than simple tangibles estimates.

4.6.. *Estimates of Global and Regional Costs*

Much work has been conducted on the analysis of direct economic losses from natural disasters. The examples mentioned below mainly focus on national and regional economic loss of particular weather extremes and disasters, and also discuss some uncertainty issues related to the economic impact assessment.

4.6.3.1. The Regional and Global Economic Loss of Climate Disasters

[Some conclusions should be reflected from Chapter 3 of the SREX report here]
Over the past decades the number and impact of reported extreme events has been increasing, both in terms of mortality and overall economic loss. In particular, the increasing trend for weather related disasters has been more pronounced than for non-weather disasters (Munich Re, 2008; Swiss Re; 2008; 2009; 2010). Some suggest that the changing frequency of extreme weather is already noticeable in loss records (e.g. Mills, 2005). Others however argue that exposure and vulnerability to different types of hazards has evolved differently over time (e.g. Kellenberg and Mobarak, 2008; Bouwer, in press).

[INSERT FIGURE 4-18 HERE:
Figure 4-18: The overall losses and insured losses from natural disasters worldwide (adjusted to present values).]

The unequal distribution of the human impact of natural disasters is reflected in the number of disasters and damage losses between regions (see Table 4-17). The Americas suffered the most economic damage from climatological, meteorological and hydrological disasters, accounting for a highest proportion of 54.6% of the total damages, followed by the Asia (27.5%) and Europe (15.9%). Africa accounted for only 0.6% of global economic damages (annual average) from climatic related disasters in the 2000-2008 (Vos et al, 2010).

[INSERT TABLE 4-17 HERE:
Table 4-17: Climate related disaster occurrence and regional average impacts from 2000-2008. Sources: Vos F, Rodriguez J, Below R, Guha-Sapir D. *Annual Disaster Statistical Review 2009: The Numbers and Trends*. Brussels: CRED; 2010. page 5-7, page25.]

When expressed as a proportion of exposed GDP, estimated losses of natural disasters (predominantly hydro-meteorological disasters) in developing regions, especially in East and South Asia and the Pacific, Latin America and the Caribbean, are several times higher than those in developed regions. This indicates a far higher vulnerability of the economic infrastructure in developing countries (UNISDR, 2009b; Cavallo and Noy 2009) (see Figure 4-19). For example, OECD countries account for 71.2% of global total economic losses of tropical cyclones, but only suffer 0.13% of estimated annual loss of GDP from 1975-2007 (UNISDR, 2009b).

[INSERT FIGURE 4-19 HERE:
Figure 4-19: Distribution of Regional damages as a % of GDP (1970-2008). Source: EM-DAT, WDI database, calculated by Cavallo and Noy (2009).]

The general consensus is that the affected regions are vulnerable both because of climate-related extremes and their status as developing regions (Burton et al. 1993). A series of developing countries, such as Argentina, Ecuador, Honduras, Nicaragua, China and Brazil, have been identified as vulnerable countries for who losses from floods could be expected to exceed or approach 1% of GDP (Swiss Re, 1998; 2009).

Studies at the global or regional level are discussed per region and for different hazards below (Bouwer, in press). The collective picture is still fragmented given the difficulty in attributing causes of fluctuations in economic losses from disasters and an imbalanced spatial coverage of literature, which is skewed mostly toward developed countries and the northern hemisphere.

4.6.3.2. Africa

The frequency and intensity of extreme events, such as floods and droughts, has increased in Africa over the past few years (IPCC, 2007). This has caused major disruptions to the economies of many African countries, thus exacerbating continental vulnerability [This section needs to align with Chapter 3] (Washington et al. 2004; AMCEN/UNEP 2002). Since 1975-2007, the estimated average annual economic loss of tropical cyclones and floods accounted for 0.55% and 0.19% of GDP respectively in affected Sub-Saharah Africa countries, which indicates a higher exposure under an increasing occurrence of disasters (UNSIDR, 2009b).

Agriculture contributes approximately 50% to Africa's total export value and approximately 21% of its total GDP (Mendlesohn et al., 2000; PACJA, 2009). With the least efficient agriculture industry in the world, increasing variability in seasons, rainfall, drought and weather extremes is making Sub-Saharan Africa extremely vulnerable. This vulnerability is exacerbated by poor health, education and governance standards (Brook, Adgar and Kelly, 2005).

Some studies project that extreme events might increase in many desert regions in southern Africa (Scholes and Biggs 2004).

Drought: One third of Africans now live in drought-prone areas, mainly in the Sahel, around the Horn of Africa and in southern Africa. Drought will also cause a decline in tourism, fisheries and cropping (UNWTO, 2003). This could reduce the revenue available to governments, enterprises and individuals, and hence further deteriorate the capacity for adaptation investment. For example, the 2003/4 drought cost the Namibian Government N$275 million in provision of emergency relief. Cameroon's economy is highly dependent on rain-fed agriculture, a 14% reduction in rainfall is projected to cause significant losses, of up to around US$4.65 billion (Molua and Lambi, 2006).

Flooding: Costly damage to African port cities from flooding, storm surge and high winds is predicted under climate change. For instance, it is indicated that in Alexandria, US$563.28 billion worth of assets could suffer damage or be lost because of coastal flooding alone by 2070 (Nicholls et al., 2007).

Ecosystems: Disasters are likely to have some negative impacts on biodiversity and the tourism industry. Projected climate impacts on Namibia's natural resources would cause annual losses of 1-6 per cent of GDP, from which livestock production, traditional agriculture and fishing are expected to be hardest hit, with a combined loss of US$461-2,045 million per year (Reid et al, 2007).

4.6.3.3. Asia

According to statistics collected by the insurance sector, about one third of reported catastrophes globally occur in Asia, while the proportion of fatalities is about 70% (Munich Re, 2008). Since 1980, more than 1 million people perished in Asia due to natural catastrophes, more than in all other continents combined (Spranger, 2008). While accounting for cultural, political and historical factors, some relationship between wealth and protection can be found in different locations in Asia. In the light of the fact that Asia is a rapidly emerging region in global economy, it would be particularly useful to incorporate climate extreme preparedness into long-term sustainable development planning. Some studies argue that economic restructuring and the process of market transition in those fast developing Asian countries could potentially help to decrease vulnerability and economic impacts of disasters (Adger, 1999; OECD, 2008).

Flooding: The geographical distribution of flood risk is heavily concentrated in Asia, especially in India, Bangladesh and China. In South Asian countries, flooding has contributed 49% to the modelled annual economic loss of GDP since the 1970s (UNISDR, 2009b). Chang et al. (2009) studied historic changes in economic losses from floods in urban areas in Korea since 1971, and found an increase in losses after correction for changes in population only. Fenqing et al, (2005) analysed losses from flooding in the Xinjiang autonomous region of China, and found an increase that seems to be linked to changes in rainfall and flash floods since 1987.

Many parts of Asia have rapid population growth and concentration of people and infrastructure in coastal areas, particularly in some of the largest cities in the world, which increases the potential losses from extreme weather events (IPCC 2001b; 2007b). Focusing on 136 large port cities around the world that have more than one million inhabitants, OECD (2008) estimated the exposure of economic assets and population to coastal flooding, and found that Asia has both a high number of cities (38%) and high exposure per city when compared to other continents. 17 Asian cities among the global top 20 largest (in terms of inhabitants) are projected to see more than a 200 per cent increase in exposure by 2015, compared to 2005. It is also estimated that, by 2015, loss potentials among the world's

10 largest cities, most of which are in developing countries, are projected to increase from 22% (Tokyo) to 88% in Shanghai and Jakarta (Bouwer et al, 2007), compared to 2005.

Typhoon: Tropical cyclone mortality risk is highly geographically concentrated in Aisa, and takes both a relative and absolute high exposure to population and GDP. For example, 75.5% of expected mortality due to typhoons is concentrated in Bangladesh and 10.8% in India. South Asian countries have an estimated average annual economic loss of $1054 million (2000 dollars) from 1975-2007 (UNISDR, 2009b). Possibly, the fast development and increasing risk awareness on some typhoon-prone areas could increase the protection levels in some developing Asian countries. This could partly explain why typhoon losses in China since 1983 do not show a trend after correction for increases in wealth (Zhang et al., 2009). Similarly, normalised losses from typhoons on the Indian south-east coast since 1977 show no increases (Raghavan and Rajesh, 2003). These findings may be exceptional and could not be used to generalise with a higher confidence since estimating an aggregate effect on long-term economic growth and welfare is difficult and controversial.

Drought: Asia has a long history of drought, which has been linked with other extreme weather events (Science Daily, 2010). In the spring of 2010 severe droughts impacted some east and southeast Asian countries, causing damages to crops, a drop in river water levels and reservoirs, and economic losses. According to China's State Commission of Disaster Relief, 51 million Chinese are affected by the drought, with estimated direct economic losses at US$2.8 billion. As reported by the Philippine Department of Agriculture's Central Action Center (DACAC), the total damages have reached US$244.4 million, with the damage in paddy rice production already nearing 300,000 metric tons (Xinua, 2010). [Peer reviewed references forthcoming]

The health sector bears a significant share of the economic burden of disasters, and health infrastructure recovers at a slower rate than infrastructure in other sectors. The emergence of infectious diseases, environmental pollutants and health inequality is likely to be exacerbated by rapid urbanisation; it is argued that health related risks could potentially worsen in Asian countries (Wu et al., in press).

4.6.3.4. Europe

Weather disasters such as flooding, droughts, forest fires and heat waves will very likely have different economic impacts across and within European Union States. Understanding how vulnerability to extreme events varies between different sectors, people and at different scales is important to analysis of economic impacts (OECD 2008; O'Brien et al, 2004).

Storms: In 2009 Europe experienced the globally highest economic loss due to extreme events. The total losses exceeded USD $20 billion, of which storms accounted for the majority of these losses. Europe also ranked in the top three regions with the highest portion of the economic loss, about 0.11% of GDP, slightly higher than the world average level of 0.10% (Swiss Re, 2010).

According to a study by Swiss Re (2009), by the end of this century once-in-a-millennium storm surge events could well be striking Northern Europe every 30 years. This is likely to result in a disproportionate increase in annual expected losses of between 100% and 900%, depending on the country. The annual expected loss burden from surge events could range from a current Euro 0.6, to 2.6 billion by end of the century. As a result, adaptation through adequate sea defenses and the management of residual risk is essential.

Sectoral impacts: Some researchers have found no contribution from climate change to trends in the economic losses from floods and windstorms in Europe since 1970s (Barredo, 2009; 2010). Some studies have found evidence of increasing damages to timber in Sweden and Switzerland (Nilsson et al., 2004; Usbeck et al., 2010). Still other studies assert that increases in forest disturbances in Europe are mostly due to changes in forest management (e.g. Schelhaas et al., 2003). Furthermore, many studies have explored the sectoral impacts in different areas of Europe caused by climate change, such as agriculture, tourism, transport, health, biodiversity and others (Fewtrell, Kay, 2008; Kenyon, 2007; Maaskant, et al, 2009; Priceputu, GreppinA, 2005;). For example, FEEM estimated the welfare impacts of the ecosystem sector, and found that they can be as much as $145-170 billion USD (Nune, Ding, 2009). Studies of the economic impact of disasters are currently inadequate and require further empirical research and methodology to investigate how extremes may impact the economy, ecosystem services, environmental amenities and human welfare. The conjunction between climatic stresses and already cited impacts on economies and society will require well-planned adaptation strategies in Europe.

4.6.3.5. Latin America

Climatic disasters account for the majority of natural disasters in Latin America, with most of its territory located in tropical and equatorial areas. Low-lying states in Central America and the Caribbean are especially vulnerable to hurricanes and tropical storms, posing significant impacts for supporting infrastructure, public safety and fragile coastal ecosystems (Lewsay et al, 2004). In October 1998, Hurricane Mitch, one of the most powerful hurricanes of the Tropical Atlantic basin of the 20th century, caused direct and indirect damages to Honduras of $5 billion USD, equivalent to Honduras' total GNP in 1998; comparatively, Hurricane Fifi caused a 1999 equivalent of $1.7 billion USD of losses in 1974 (IMF 1999).

Some literature indicates that hurricane losses, when corrected for population and wealth in Latin America and the Caribbean have not increased since the 1940s (Pielke et al. 2003); and that increasing population and assets at risk are the main reason for increasing impacts. Nonetheless it is likely that natural disasters will remain a significant external shock to economies in this region in the next decades.

4.6.3.6. North America [only covers USA, further analysis on Canada and Mexico forthcoming]

Hurricanes and storms: Given the extremely large losses and importance for the national and international insurance industries, losses from hurricanes in the USA have been studied extensively. Since the 1970s an increase in losses is observed and this is related to the increase in hurricane activity since that time, largely attributable to natural variability. It is reported that the direct overall losses of Hurricane Katrina are about US$ 138 billion in 2008 dollars (Spranger, 2008). [Hurricane information needs to be brought in line with other chapter info on hurricane strength and frequency]

With a normalization procedure (principally corrections for wealth and population), some studies have found similar conclusions that no trends are found in the normalized loss record over the entire length of the record (starting in approximately 1900) (Collins and Lowe, 2001; Pielke et al., 2008; Miller et al. , 2008; Malmstadt et al., 2009; Schmidt et al., 2009).

Malmstadt et al. (2009) and Schmidt et al. (2009) however maintain that an anthropogenic climate change signal can be found in the normalised loss record for hurricanes. For example, since 1971-2005 economic losses of cyclones show an annual increase of 4% excluding socio-economic effects (Schmidt et al., 2009). Changnon (2009b) indicates that normalized insured losses from windstorms in the USA have increased, but only in areas where population and capital are concentrated most heavily. Changnon (2003) reveals annual average losses of $36 billion from extremes and gains averaging $26 billion when conditions are favourable (good growing seasons, mild winters, etc). Compared with various measures and values, it has been found that the impacts are relative small, typically about 1% of GDP.

Other extreme events: Smaller scale but more frequent storms events can together cause substantial losses. Changnon (2001) found increases in normalised losses from various thunderstorm storm events in the USA (hail, lightning, high wind speeds and extreme rainfall), but also in areas where no increase in thunderstorm activity occurred. This is also true for losses from tornadoes (Brooks and Doswell 2001; Boruff et al. 2003). This suggests there may be other causes for these loss increases. Changnon (2009a) finds similar conclusions for hail storm losses. Similarly, there are indications that flood losses in the USA have not increased since 1926 (Downton et al., 2005).

Weather stress: Chronic everyday hazards such as severe weather (summer and winter) and heat account for the majority of natural hazard fatalities. It has evidence that heat- and cold-related extreme weather is probably the deadliest weather hazards in the U.S based on a geographical and epidemiological research since 1970s (Borden, Cutter, 2008).

4.6.3.7. Oceania (Australia, New Zealand and Pacific Island Countries)

The Oceanic region, including Australia, New Zealand and the Pacific Island countries (PICs) is geographically, economically and socially diverse. Due to this diversity it is appropriate to briefly consider these three sub-regions individually.

Australia: The International Disaster Database (EM-DAT, 2010) estimates the total cost of disasters in Australia between 1970 and 2009 to be approximately $29 billion USD. The burden of disasters in Australia is not evenly spread, as a few large events dominate the overall cost, including Cyclone Tracy in 1974, the Newcastle Earthquake in 1989 and the Sydney hailstorm in 1999. Overall floods (29%), severe storms (26%) and tropical cyclones (24%) are the most costly natural disaster types in Australia. Bushfires in Australia are the most dangerous in terms of death and injury, however they only account for approximately 7.1% of the economic burden of disasters in the 1967-1999 period (BTE, 2001).

The cost of disasters is believed to be increasing in Australia; Crompton and McAneney (2008) found that the cost of insured losses is increasing over time. However, they found that the increase in insured losses over time can largely be explained by demographic and societal changes, rather than climate change.

Australia is predicted to experience an increased cost of disasters if current population growth continues, with the corresponding increase in the number and value of dwellings (Crompton and McAneney, 2008). Climate change is concurrently expected to increase the frequency and severity of extreme weather events (Alexander and Arblaster, 2009). These factors will converge to increase the cost, financial, social and environmental, of disasters in Australia unless disaster adaptation and mitigation efforts are increased.

New Zealand: Aggregates of the total cost of natural disasters in New Zealand are not easily estimated due to earlier lack of data collection and may be underestimated (BTE, 2001). EM-DAT (2010) estimated the total economic cost between 1970-2009 to be approximately $1 billion USD. Floods were the most common type of disaster in New Zealand, accounting for 43 % of the total number of events (BTE, 2001).

PICs: The southwest Pacific experiences periodic drought and extreme sea levels, largely due to El Niño-Southern Oscillation and El Niño events. Coastal areas in PICs also experience tropical cyclones, accompanied by high winds, storm surges and extreme rainfall (World Bank, 2000). EM-DAT (2010) estimates the cost of disasters in PICs between 1970 and 2009 to be approximately $3 billion USD. Three Pacific disasters are in the top ten disasters (1974-2003) for cost as a proportion of GDP, with the 1985 cyclone in Vanuatu costing approximately 139% of national GDP. This highlights how devastating disasters can be to small, developing countries (Guha-Sapir *et al, 2004).*

Not only are disasters in PICs devastating but they are also relatively frequent. Oceania accounted for 8% of all the disasters registered with EM-DAT between 1990 and 1999 (Alcántara-Ayala 2002, pg. 112), this indicates a significant burden of disasters considering the tiny proportion of global population that resides in PICs.

PICs are vulnerable to natural disasters for several reasons. Small islands are susceptible to disasters induced by extreme rainfall events. The small size of many PIC islands further compounds disaster risk because of a small natural resource base and a high concentration and competition for land use (Preston *et al*, 2006; Pelling and Uitto, 2001). PICs economies tend to be dominated by agriculture, which is particularly vulnerable to natural hazards (Narayan, 2003). Despite perceived vulnerabilities, Pacific Island peoples have a traditional resilience to disasters and have practising disaster risk management since pre-colonial times. Profound changes in the social, economic, cultural and political fabric of PICs have led to a decline in traditional disaster management practises (Campbell, 2006; Campbell, 2009). Much of this traditional resilience remains and could be reinvigorated within the current context to reduce vulnerability.

4.6.4. The Regional and Global Costs of Adaptation

Adaptation studies for developed and developing countries have focussed on the costs of adaptation rather than impacts and damage costs of extremes, with many studies not explicitly separating extreme events from slower onset events (see Parry et al., 2009; World Bank , 2009; EEA, 2007; ECA, 2009; Solomon 2007; Nordhaus, 2007; Parry et al., 2009; Agrawala and Fankhauser, 2008). Those studies considering extreme events, and finding or reporting net benefits over a number of key options (Parry et al., 2009; Agrawala and Fankhauser, 2008) do so by treating it in a similar way to gradual onset phenomena and use deterministic impact metrics, which is problematic for disaster risk. A recent, risk-focussed study (ECA, 2009) went so far as to suggest an adaptation cost curve, which organizes adaptation options around their cost benefit ratios with most cases in this report looking at sub-national level and one on national level adaptation.

One study (World Bank, 2009) aggregating at the sub-continental level with a focus up to 2050, specifically calculated adaptation costs for dealing with changes in extreme events; they estimate an annual value of about $6.5 billion USD. National level studies in the EU in the UK, Finland and the Netherlands as well as a larger number of developing countries using the NAPA approach have been conducted or are underway (Lemmen et al, 2008; MMM, 2005; Van Ierland, 2005; DEFRA, 2006; Parry et al., 2009). However the evidence base on the economic aspects, including economic efficiency, of adaptation remains limited and fragmented (Adger et al., 2007; Agrawala and Fankhauser, 2008; Moench et al., 2009; Parry et al., 2009).

Adaptation cost estimates can be split into four major categories (UNFCCC, 2007; SEI, 2008; PACJA, 2009): (i) Assessing vulnerability (building on assessments contained in NAPA); (ii) Building institutional capacity (climate information, skilled professionals, and so on); (iii) Piloting adaptation strategies; and (iv) Operational adaptation (needed to cope with new hazards and conditions). The existing estimates of adaptation cost have some weakness in methodology: a) omission of some economic sectors, such as ecosystems, tourism, etc, and b) a lack of consideration for “adaptation deficit” which is relevant to climate proof investment (PACJA, 2009).

It is necessary to incorporate an analysis of the chronic economic impact of catastrophes into the adaptation planning process (Freeman, 2000). A full assessment of disaster cost at varying spatial and temporal scales can set the stage for comparisons of post-disaster development strategies, which would make DRR planning and preparedness investment more cost-effective (Gaddis, et al, 2007). Also, costs of climate disasters can impact human, social, built and natural capital, and their associated services at different levels. For example, a cost estimate for financial vulnerability would represent a baseline for the incremental costs arising from future climate risks (Mechler et al, 2010). There is consensus on the important role of ecosystems on risk reduction and well-being, which makes the value of ecosystem services an integral part of key policy decisions (Costanza, Farley, 2007; Tallis and Kareiva, 2006).

Taking Africa as an example, based on various estimates the potential additional cost of climate proofing new infrastructure would likely amount at a range of US$3-10 billion per year by 2030 (Reid et al., 2007; UNFCCC, 2007; PACJA, 2009). However, this could be also an underestimate considering an increasing climate protection for improving Africa’s low resilience to climate extremes as well international humanitarian aid in the aftermath of disasters. For example, OECD (2007) has estimated that assets valued at over half a trillion dollars in one city (Alexandria in Egypt) alone could suffer damage or be lost because of coastal flooding.

4.6.5. Uncertainty in Assessing the Economic Loss of Extremes and Disasters

Upon reviewing the estimates to date there is a consensus that the state of art of costing climate change related disasters is still preliminary, incomplete and subject to a number of assumptions (Parry et al, 2009; Agrawala and Fankhauser, 2008; Tol, 2005). This is largely due to not only modelling accuracy in climate science and damage estimates, but also in the interaction between adaptation options with future vulnerability and resilience in a specific society.

Climate modeling and future vulnerability. Climate models are not good at reproducing spatially explicit climate extremes yet, due to inadequate (coarse) resolution. Hence projections of extreme events for future climate conditions are highly uncertain and this is often an important hindrance to robustly projecting sudden onset risk, such as flood risk; while drought risks, which are a slower onset phenomena more strongly characterised by mean weather conditions, can better be projected (Christenson, 2003; Kundzewicz et al., 2006).

Apart from climate change, vulnerability and exposure will also change over time, and these aspects of the risk triangle are often not considered equally (see Mechler and Hochrainer, 2010; Hallegatte, 2008). However, important progress is being made in terms of risk based assessments, with the climate change modelling community embracing a more risk-based approach (see, for example, Jones, 2004; Carter et al., 2007). It has also been noted that assessments of climate change impacts and vulnerability have changed in focus from an initial analysis of the problem to the assessment of potential impacts, and finally to the consideration of specific risk management methods (Carter et al., 2007).

*Attribution of economic losses and climatic disasters***.** An important question is to what extent historic losses from disasters can be attributed to anthropogenic climate change. Some studies claim that climate change can be found in records of disaster losses (e.g. Mills, 2005; Höppe and Grimm, 2009; Malmstadt et al., 2009; Schmidt et al., 2009). Others however argue that the role of non-climatic factors (increasing exposure of people and capital) in the observed increase is so large, that any changes in extreme weather incidence cannot be identified (Changnon et al., 2000; Pielke et al., 2005; Bouwer et al., 2007). Also, a particular difficulty encountered in these studies is the attribution of loss changes to anthropogenic climate change. As the incidence of disasters varies with natural climate variability, large variations can be seen in economic losses over decades even without anthropogenic climate change (Pielke and Landsea, 1999; Bouwer, submitted). The attribution of losses to anthropogenic climate change requires long time series, and the analysis needs to take into account natural variability.

A series of scientific studies [references forthcoming] have attempted to detect changes in time series of observed direct losses for particular natural hazards and particular countries or regions, and attribute these changes to both climatic and non-climatic causes. Many of these studies apply a so-called ‘normalization’ procedure (Pielke and Landsea, 1998) to the loss record that accounts for changes in exposure and vulnerability, in order to keep these constant over time (many of these studies have been included in Section 4.6.3.1 above). Typically, these procedures correct the loss record for inflation, population and wealth or capital growth in the disaster affected locations, and show losses from individual events as if they occurred in the same year. This allows observing changes in the weather hazard, rather than the disaster impact.

In general, studies at the local and regional level have found no trend in normalized losses for windstorms (including typhoons and hurricanes; see Section 4.6.3.1). For precipitation related events (intense rainfall, hail and flash floods), the picture is probably more diverse; some studies suggest increase related to a changing incidence in extreme precipitation (Changnon, 2001; Changnon, 2009a; Chang et al., 2009; Fenqing et al., 2005). However, uncertainties in these studies are large as well, given the different normalization procedures, and subtleties in changes in exposure to flooding over time and other non-climatic factors that increase flood frequency that are not always accounted for. The IPCC WG2 Fourth Assessment Report (Wilbanks et al., 2007) discussed a study that has analysed a normalized record of global weather losses. This study did not find sufficient evidence for an economic trend that could be accounted for by anthropogenic climate change (Miller et al, 2008). In conclusion, there is only very limited evidence that anthropogenic climate change has lead to increasing losses; increasing exposure is the main reason for long term changes in economic losses.

With specific reference to river flooding, there is considerable evidence, mostly from the insurance and reinsurance industry (e.g. ABI, 2005), that the economic losses from flood events have generally increased over time (although not everywhere: Miller et al., 2008). However, this trend can be explained almost entirely by changes in socio-economic drivers of flood loss, including increased occupation of flood-prone areas and the increasing value of assets exposed to flood. Pielke and Downton (2000) examined US national flood damage data over the period 1932-1997, normalising trends for increasing population and GDP, and found no evidence of trend. Barredo (2009) examined normalised flood loss data from major European floods, again finding no trend. Data on flood losses are, however, unreliable – particularly for individual, small events (Downton et al., 2005) – and losses from the multitude of small events are probably underestimated. Several authors (e.g. Downton et al., 2005; Merz et al., 2010) call for improved data collection in order to clarify the extent of trends in flood loss.

4.6.6. Comment on the Likely Impact on the Global Loss Figure of a 4°C Rise

Over the last few years, a substantial literature has emerged that has projected potential disaster losses under future climate change. A range of approaches have been utilised, including economic modelling (usually CGE modelling), which include economic impacts beyond the direct damages. Approaches that combine climate models with catastrophe models are more detailed in describing physical processes, but are more limited with regard to cost categories (see also the discussion in Section 4.6.1.1). Also, a number of studies have used simplified approaches for future hazard loss estimation that include simple factor changes in hazards instead of full climate scenarios. In general, few studies have specifically applied a scenario of the impact of a global average 4°C warming. Also, most studies address regional impacts, rather than global aggregate impacts.

Some 4 degree studies are not focused on extremes but rather on slower onset changes in average climate. For example, drought is one of the most serious hazards for Africa's agricultural sector in certain areas. Based on business-as-usual A2 scenario, PACJA predicts with PAGE model that the annual economic costs of climate change in Africa with a 4°C mean temperature rise could be equivalent to 10 per cent of GDP (PACJA, 2009). By 2100, regions of arid and semi-arid land are expected to expand by 5-8 per cent, or 60-90 million hectares, resulting in agricultural losses of between 0.4-7 per cent of GDP in northern, western central and southern Africa (IPCC, 2007).

Agriculture: 4°C rise is predicted to cause a decrease in crop productivity for all cereals (IPCC WGII, 2007) and could result in a net revenue losses of US$95.7/ha in Africa (Nkomo et al., 2007). Take Kenya as an example, losses for mangoes, cashews and coconuts could reach US$472.8 million (Republic of Kenya 2002, in Stern 2006).

Health: Weather based disasters have been described as a significant and emerging threat to public health, particularly in developing countries where it can cause increased morbidity and mortality from common vector-borne diseases such as malaria and dengue, as well as other major killers such as malnutrition and diarrhoea. Climate change is already contributing to the global burden of disease, and this contribution is expected to grow in the future (WHO, 2008). A 4°C rise would see an increasing burden from malnutrition, diarrhoea, cardio-respiratory and infectious diseases, as well increased morbidity and mortality from heat waves, flooding and droughts. It is estimated that by 2080s more than 128 million people would be at risk from hunger (PACJA, 2009). Under a scenario assuming emissions reductions resulting in stabilization at 750 ppm CO2 equivalent in 2210, it is estimated that the climate change attributed cases of diarrhoeal disease, malnutrition and malaria in 2030 would increase by 3%, 10% and 5% respectively comparing with the current cases. The total costs of treatment were estimated to be $4 to 12 billion (Ebi, 2008). This is almost as much as current total annual overseas development assistance for health.

Some studies predicted the future risk from weather disasters. Below a number of studies are discussed, that translated changes in projected hazard frequency and intensity into economic losses.

Tropical storms: The projections of losses from tropical storms largely depend on a) estimated change in frequency and/or intensity of hurricanes due to global warming; and b) the estimated statistical relationship between maximum wind speed and losses. Some studies use high projections in cyclone activity and a high loss response, and therefore project substantial changes of between a 30 and 60% increase in losses by 2040 for different regions, including the Atlantic, Caribbean, and Asia (ABI, 2005a; ABI, 2005b; Narita, 2009; Nordhaus, 2010). Others however estimate these changes to be substantially smaller, in the order of 10-20% increase by 2040 (Hallegatte, 2007; ABI, 2009; Schmidt et al., 2009). In a recent study, Bender et al. (2010) use a series of GCM ensembles, and estimate hurricane losses to increase some 30% by the end of this century, with ranges between -50 and +70%. Pielke (2007) tested extreme cases, and arrived at what can be considered upper end estimates of 50-1350% increases by 2040.

Extra-tropical storms: The projections of losses from mid- and high-latitude extra-tropical storms has been generally approached by combining wind fields of GCMs with damage models (Leckebusch et al., 2007; ABI, 2005a; ABI, 2009; Schwiertz et al., in press). Most studies have been done for Europe or European countries including UK, France, Germany and Netherlands. These studies find moderate impacts (compared to extra-tropical cyclone losses) from climate change of between 10 and 20% increases by 2040 (Leckebusch et al., 2007; ABI, 2005a; ABI, 2005b; ABI, 2009; Narita et al., 2010; Schwiertz et al., in press), except for Dorland et al. (1999) who applied relatively large increases in projected wind speeds for The Netherlands. The study by Narita et al. (2010) has applied an economic model, rather than a GCM approach, but arrives at similar estimates, and results are for worldwide extra-tropical storm losses.

Floods: Many studies have addressed future economic losses from river floods, most of which are focused on Europe, including the UK (Hall et al., 2003; Hall et al., 2005; ABI, 2009), Spain (Feyen et al., 2009), and Netherlands (Bouwer et al., 2010). Feyen et al. (2009) project loss increases for a range of European countries. Schreider et al. (2000) find substantial increases in future losses due to flash floods in Australia. Maaskant et al. (2009) is one of the few studies that projects loss of life from flooding, and projects up to a fourfold increase in potential flood victims in the Netherlands by the year 2040, when population growth is accounted for.

Other weather extremes: Some studies have addressed economic losses from small-scale weather extremes. These include hail damage, for which mixed results are found: McMaster (1999) and Niall and Walsh (2005) found no significant effect on hailstorm losses for Australia, while Botzen et al. (2010) find a significant increase (up to 200% by 2050) for damages in the agricultural sector in the Netherlands, although the approaches used vary considerably. Rosenzweig et al. (2002) report on a possible doubling of losses to crops due to excess soil moisture caused by more intense rainfall. Hoes (2007), Hoes and Schuurmans (2006), and Hoes et al. (2005) estimated increases in damages due to extreme rainfall in the Netherlands of some 30% by 2040.

Role of factors other than climate change: It is well known that the frequency of weather hazards is only one factor that affects total risks, as changes in population, exposure of people and assets, and vulnerability determine loss potentials. But few studies have addressed these factors. However, the ones that do generally underline the important role of projected changes (increases) in population and capital at risk. Some studies indicate that the expected changes in exposure are much larger than the effects of climate change, which is particularly true for tropical and extra-tropical storms (Pielke et al., 2007; Feyen et al., 2009; Schmidt et al. 2009b). Other studies show that the effect of increasing exposure is about as large as the effect of climate change (Hall et al., 2003; Maaskant et al., 2009; Bouwer et al., 2010), or estimate that these are generally smaller (Dorland et al. 1999; Hoes, 2007). Finally, many studies underline that both factors need to be taken into account, as the factors do in fact amplify each other, and therefore need to be studied jointly when expected losses from climate change are concerned (Hall et al., 2003; Bouwer et al., 2007; Pielke, 2007; Feyen et al., 2009; Bouwer et al., 2010).

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Case Study – Darfur Conflicts and the Role of Climate Change

Is the conflict in Darfur the first climate change war? asked economist and *Scientific American* columnist Jeffrey Sachs at an event at Columbia University in 2007 (Sachs, 2008). “Don’t doubt for a moment that places like Darfur are ecological disasters first and political disasters second.”

But new research would suggest the answer to Sachs's question is no, at least regarding the novelty of Darfur. Agricultural economist Marshall Burke of the University of California, Berkeley and his colleagues have analyzed the history of conflict in sub-Saharan Africa between 1980 and 2002 in a new paper (Burke *et al*., 2009).

"We find that civil wars were much more likely to happen in warmer-than-average years, with one degree Celsius warmer temperatures in a given year associated with a 50 percent higher likelihood of conflict in that year," Burke says (see also Biello, 2008). The implication: because average temperatures may warm by at least one degree C by 2030, "climate change could increase the incidences of African civil war by 55 percent by 2030, and this could result in about 390,000 additional battle deaths if future wars are as deadly as recent wars."

In fact, temperature change offered a better prediction of impending conflict in the 40 countries surveyed than even changes in rainfall (Sachs, 2006), despite the fact that agriculture in this region is largely dependent on such precipitation. Burke and his fellow authors argue that this could be because many staple crops in the region are vulnerable to reduced yields with temperature changes—10 to 30 percent drops per degree C of warming.

"If temperature rises, crop yields decline and rural incomes fall, and the disadvantaged rural population becomes more likely to take up arms," Burke says. "Fighting for something to eat beats starving in their fields."

Whereas 23 years in 40 countries provides a relatively large data set, it does not exclude other possible explanations, such as violent crime increasing with temperature rise, a drop in farm labor productivity or population growth. "Fast population growth could create resource shortage problems, as well," notes geographer David Zhang of the University of Hong Kong, who previously analyzed world history back to A.D. 1400 to find linkages between war and temperature change (Zhang *et al.*, 2007). But "the driver for this linkage," Zhang says," is resource shortage, mainly agricultural production, which is caused by climate change."

Burke and his colleagues specifically excluded records from prior to 1980, because of the conflict rampant in the wake of Africa's emerging colonial independence after World War II. "A lag of a couple of decades would leave sufficient time for post-independence turmoil to wear out," Burke argues. "We took the approach that the best analogue to the next few decades were the last few decades."

Proving the link—and providing a specific mechanism for the increase in conflict, whether agricultural productivity or otherwise—remains the next challenge. "I believe that the historical experience of human society of climate change would provide us [with] the evidence of how climate cooling and warming during the last thousand years created human crisis, and also the lessons for human adaptive choices for climate change," Zhang notes.

"We feel that we have very clearly shown the strong link between temperature increases and conflict risk," Burke adds. But "what interventions will make climate-induced conflict less likely?

The U.S. military, for its part, is concerned about the issue, analyzing the possibility for climate change to destabilize countries in recent reports, such as an essay from members of the CNA Military Advisory Board in November, "Climate and Energy the Dominant Challenges of the 21st Century" (Wald, Goodman and Catarious, 2009).

In April 2007, 55 delegations to the UN met at the Security Council to discuss the security implications of climate change. Led by the then UK Foreign Secretary, Margaret Beckett, states shared their concerns about the security implications of climate change. UN Secretary General Ban Ki-moon talked of scarce resources, fragile ecosystems and severe strains placed on the coping mechanisms of groups and individuals, potentially leading to "a breakdown of established codes of conduct, and even outright conflict.

A decline in water supplies for drinking and irrigation, a decline in agricultural productivity as a result of changes in rainfall, temperature and pest patterns, and large economic and human losses attributable to extreme weather events will all take their toll on the global system as a whole.

Some western governments are concerned that these conditions will create an unstable world and may lead to a subsequent rise in terrorist activity. What is more likely, I argue, is a potential rise in conflict in the most environmentally and politically vulnerable states. International Alert, a peace-building organisation, has identified 61 countries they perceive as being at risk from the ‘double-headed' risk of climate change and conflict (Smith, 2007).

This article will specifically examine the potential rise in three types of conflict as a result of climate change:

- Political violence
- Inter-communal violence
- Interstate warfare

This article does not argue that climate change will directly cause conflict in the future. It argues that the environment (as a result of climate change) will become a more prominent factor in the outbreak of conflict.

Changes in the environment alone will not result in conflict. They need to be combined with existing divisions within society, be they ethnic, nationalist or religious. As Idean Salehyan (Salehyan, 2007) argues, there is much more to armed conflict than resource scarcity and natural disasters. However, that doesn't mean that resources and changes in the environment should be excluded as potential factors in the outbreak of conflict.

Political Violence

An April 2007 report by the Military Advisory Board of the CNA Corporation, a US-based think tank, seeks to make explicit the link between climate change and terrorism. In the report, retired Admiral T. Joseph Lopez states that "climate change will provide the conditions that will extend the war on terror" (CNA Corporation, 2007). This statement is based on the premise that greater poverty, increased forced migration and higher unemployment will create conditions ripe for extremists and terrorists (CNA Corporation, 2007). Although there is a well-established link between economic disadvantage and civil unrest, this does not necessarily manifest itself through terrorism.

The likelihood of increased terrorism

There are a number of reasons why it is unlikely that climate change will lead to an increase in terrorist activity, at least in the short-term. Firstly, terrorism tends to be a response to a perceived and visible injustice committed by a tangible group or government against a particular group of people. In addition, individuals or groups tend to resort to violence if other avenues are unavailable or perceived as not working.

Environmental change will be difficult to attribute to a specific group of people or a state, and the changes will take place over such a timescale that they won't be instantly visible. This may not stop organisations and states from being targeted, however those involved may merely want to bring attention to issues, knowing that they will not be able to solve the problem through violent action.

Secondly, varied and diverse aims of groups affected by climate change make organised international terrorism as a response to climate change is highly unlikely. The actions of a group in the Middle East campaigning for access to water will be unlikely to improve the situation for those suffering severe flooding in Asia. If terrorism and civil unrest do occur they are likely to be on a local, perhaps regional scale.

Instead of focussing on environmental groups and tightening anti-terrorist laws, governments should be focussing on ways to both curb and mitigate the effects of climate change. Their attention should also turn to less developed countries, who stand to suffer the worst of climate change and who lack the capacity to be able to respond effectively. Climate change in less developed countries is not likely to lead to terrorism, but to conflict.

Inter-Communal Conflict

At the most basic level, we all depend on the natural environment for our survival. It is the sole provider of the most basic of human needs: food, water and shelter. Global warming and the resulting changes in the environment will affect our ability to meet these needs. Conflict as a result of climate change is likely to emerge if a) the carrying capacity of the land is overwhelmed, or b) as a result of competition over specific resources.

Carrying capacity

Carrying capacity is defined as the maximum number of people an area can support without deterioration. Climate change will alter the carrying capacity of many vulnerable areas of the world either as a result of land degradation (flooding, drought and soil erosion) or the pressures of migration. "If there is a choice between starving and raiding, humans raid," according to Harvard archaeologist Dr. Steven LeBlanc. The most combative societies are therefore often the ones that survive.

Many climate change scientists predict that there will be a "significant drop in the carrying capacity of the Earth's environment" which could potentially lead to the sort of Hobbesian state which LeBlanc describes.

There is already growing evidence to support the theory that the current conflict in Darfur is partly due to land degradation as a result of climate change. Less than a generation ago, Africans and Arabs lived peacefully and productively in Darfur. More recently, desertification and increasingly regular drought cycles have diminished the availability of water and arable land, which has in turn, led to repeated clashes between pastoralists and farmers.

Dr. John Reid, then British Defence Secretary, speaking in March 2006 stated that "the blunt truth is that the lack of water and agricultural land is a significant contributory factor to the tragic conflict we see unfolding in Darfur."

Rainfall has declined by up to 30% in the last 40 years and the Sahara is currently advancing at over a mile per year. The potential for conflict over disappearing pasture and evaporating water holes is huge. The southern Nuba tribe have warned they could restart the half-century war between North and South Sudan because Arab nomads (pushed into their territory by drought) are cutting down trees to feed their camels.

Migration
Environmental-related migration between and within states may increase existing tensions and/or create new ones, potentially leading to conflict. This issue will primarily affect underdeveloped states as weak infrastructure, resource scarcity and income disparity increase the risk of migration-related conflict. Poverty and resource scarcity are exacerbated by an influx of immigrants, especially if environmental migrants worse existing tensions and divisions within society (ethnic, national or religious).

However, conflict will only occur if the receiving area is unable to deal with the migrants.

Interstate Warfare
Environmental-based conflict can also erupt as a result of competition over an abundance of a commercially valuable resource located in a particular area. Resources are not distributed evenly and do not follow internal or external boundaries and resource-based conflict can happen between states as well as within them.

Conflict over resources is not confined to oil, however. ‘Water wars’ are set to increase as water levels decline and rapidly growing populations place increasing pressure on water supplies.

Forewarned is forearmed
This article paints a grim picture of disputes over precious resources, the erosion of fragile ecosystems and a world dominated by conflict. The real question to ask is not how likely is this to happen, but what can we do to prevent it happening and how can we mitigate the effects.

Margaret Beckett, then UK Foreign Secretary, argued in a speech at the Royal United Services Institute that in the world of military security, planners prepare for the worst-case scenario; they don't wait to see what might happen. The same approach is required for climate change. Preparing for the security implications of climate change means both acting to make these events less likely and also strengthening state capacity to deal with the effects.

This doesn't mean (as some analysts have suggested) adopting a ‘fortress mentality', shoring up our borders and increasing our defensive capacity, but instead focusing on ways in which resources can be effectively managed and distributed.

We also need to ensure that the socio-economic resilience of those states most vulnerable to the direct effects of climate change is strengthened and that the global system as a whole is prepared for potentially huge global changes. The meeting at the UN held in April was a step in the right direction. Climate change needs to be permanently placed on the UN's agenda. Many states in attendance were in support of the Security Council addressing the issues, citing Resolution 1625, concerned with the prevention of armed conflict, in support of the meeting.

Many more states, particularly the powerful and developed nations, need to be convinced of the importance of the issue and to act on climate change before it creates global conflict. The irony of climate change is that although the more developed states are the main polluters, less developed states will suffer most and have the least capacity to respond effectively to climate change. Many already suffer from poverty, resource scarcity, health crises and ethnic/religious/national tensions and are dependent on the natural environment. These factors make them more prone to conflict as a result of climate change and lessen their ability to adapt to environmental change.

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Table 4-1: Sidr versus Nargis: general figures

Characteristics	**Sidr 2007 (Bangladesh)**	**Nargis 2008 (Myanmar)**
Date of landfall	15 November 2007	2 May 2008
Tropical cyclone max. category	5	4
Tropical cyclone max. category on land	4	3
Maximum windspeed	245 Km/h (68 ms^{-1})	235 (> 65 ms^{-1})
Storm surges height	5 – 6 m	4
Total population exposed (PREVIEW)	10,562,200	8,465,300
Cyclone duration		?
Total GDP exposed	?	2,147,500,000
Total Affected (EM-Dat)	8,978,541	2,420,000
Killed	4,234	138,366
Estimated damages (in millions US$)	2300* (1.7 billion)**	4000
Shelters at time of the cyclones	3976	?
Number of people evacuated	3.2 millions	?
Percentage of people aware of cyclone prior to landfall	86%	?
Volunteers for warning	43,000	?

Compiled from CRED 2009, Paul 2009, Webster 2008 **[missing some values: to be completed]**

Table 4-2: Factors to be considered in this section.

Hazard	**sector and system**	**region**
heatwave	freshwater resources	Africa
coldwave?	terrestial and inland water systems	Europe
flood due to heavvy rain	coastal systems and low-lying areas	Asia
GLOFs	ocean systems	Australia
drought due to dry weather	food production systems and food security	North America
ENSO	urban areas	Central and South America
bush/forest fire	rural areas	Polar regions
landslide following heavy rain	key econoimc sectors and servicies	Small islands
cyclone(strong wind&rain)	human health	Open oceans
cryosphere	human security	
sea level rise	livelihoods and poverty	

Table 4-3: Yearly average human exposure to tropical cyclones in 1970.

Tropical Cyclones	**1970**				
Region	**Cat1**	**Cat2**	**Cat3**	**Cat4**	**Cat5**
Africa	665311	234786	84404	2983	0
Asia + Pacific	30018234	6730459	2581252	295333	26308
Europe	147154	34598	847	0	0
Latin America + Caribbean	999431	369094	206353	126451.	36755
North America	1795531	385926	268477	42066	0

Source: Peduzzi *et al.*, 2009

Table 4-4: Yearly average human exposure to tropical cyclones in 1990

Tropical Cyclones	**1990**				
Region	**Cat1**	**Cat2**	**Cat3**	**Cat4**	**Cat5**
Africa	1053320	383620	137256	5137	0
Asia + Pacific	41555940	9235975	3535603	413795	39093
Europe	157026	36568	1002	0	0
Latin America + Caribbean	1392138	511176	279134	186204	58611
North America	2187398	470306	327031	51309	0

Source: Peduzzi *et al.*, 2009

Table 4-5: Yearly average human exposure to tropical cyclones in 2010

Tropical Cyclones	**2010**				
Region	**Cat1**	**Cat2**	**Cat3**	**Cat4**	**Cat5**
Africa	1769951	654177	232848	9181	0
Asia + Pacific	51161149	11327859	4347756	516308	51057
Europe	173870	40789	1081	0	0
Latin America + Caribbean	1722069	629207	341603	244147	81042
North America	2724747	585767	407402	63885	0

Sources: Peduzzi *et al.*, 2009

Table 4-6: Yearly average human exposure to floods in 1970, 1990 and 2010

Regions	HE_1970	HE_1990	HE_2010
Africa	588'019	1'009'604	1'658'154
Asia + Pacific	23'436'375	36'930'541	51'216'040
Europe	954'525	1'083'212	1'095'893
Latin America + Caribbean	554'997	852'419	1'148'162
North America	297'546	363'949	452'645
West Asia	20'631	38'975	68'375
Total human exposed	25'852'092	40'278'701	55'639'268

Source: Peduzzi *et al.*, 2009

Table 4-7: Coastal systems: summary table of observed and predicted exposure trends

Coastal systems	Current exposure	RSLR	Storm surges	Storm waves	Extreme rainfall	Sediment supply changes
Beaches	X	XX	XX	XX	-	XX (if negative)
(Soft) seacliffs	X	XX	XX	XX	XX	-
Deltas	X	XX	XX	XX	xx	XX (if negative)
Estuaries	X	XX	XX	xx	thr	XX
Saltmarshes	X	thr	o	XX	-	thr
Mangroves	X	XX	xx	xx	-	xx (if negative)
Coral reefs	X	-	-	XX	XX	XX (if positive)
Seagrasses	x	-	-	-	xx	-

Key: X large exposure; x, moderate exposure; XX, large change in predicted exposure; xx, moderate change in predicted exposure; -, small or not established change in predicted exposure; thr, future exposure depends on thresholds; o, future exposure depends on many other environmental parameters; RSLR, Relative sea level rise. Note: The predicted effects on coral reef exposure are based only on sea level rise considerations and not on potential increases in seawater temperatures.

Table 4-8: Current and future population exposure in low elevation coastal zones

Region	**Area** (10^3 km^2)	**Population expos. (current)** (millions)	**Population expos. (2050 no tipping)** (millions)	**Population expos. (2050 with tipping)** (millions)
Africa	191 (1)^1	2.80	3.76 (34%) ^{2}	5.77 (106%)^2
Asia	881 (3)	47.76	60.15 (26%)	82.68 (73%)
Europe	490 (2)	9.56	11.70 (22%)	16.42 (72%)
Latin America	397 (2)	4.60	5.57 (21%)	7.45 (62%)
N. America	553 (3)	4.82	6.25 (30%)	8.88 (84%)
Oceania	131 (2)	2.00	2.26 (26%)	2.68 (49%)
SIS	58 (16)	n/a	n/a	n/a
Total	**2700 (2)**	**71.35**	**89.70 (26%)**	**123.87 (74%)**

Low Elevation coastal areas (LECZ) (McGranahan et al., 2007), current and future (2050) population exposure to inundation in the case of the 1-in-100-yr extreme storm under 'normal projections' (SLR of 0.15 m) and 'tipping projections' (SLR 0.50 m, due to the partial melting of the Greenland Ice Sheet (GIS) and West Antarctic Ice Sheets (WAIS) (Lenton et al., 2009). The numbers in parentheses refer to: ^{1}, percentage of total land area; ^{2}, increase (%) in exposure relative to population presently exposed. Note: Projections refer to current population i.e. not accounting for population growth by 2050. Key: SIS, Small Island States.

Table 4-9: Trend of water-related disasters from 1980 to 2006 by hazards (based on Adikari and Yoshitani (2009))

Total/General	Increase in every region. Linear increase more than double in Asia and more than four-fold in Africa.	Decreasing trend with occasional peaks.	In general, the estimated water-related economic losses globally show an increasing trend. The trend had a trough during the period 2001 to 2003, and then increased sharply until 2006. The increase was due to the huge economic damage caused by Hurricane Katrina in the United States in 2005. Among water-related disasters, windstorms, floods and droughts are the main contributors to economic losses – in descending order – and the rest of the water-related disasters are insignificant but underestimated. The estimates of economic losses caused by water related disasters in different parts of the world may not be entirely reliable, because the values obtained from different countries are derived under different definitions and using different estimation methods, monetary units and purchasing power. Furthermore, some countries do not carry out surveys or keep proper records, while others may keep their records confidential. Reported figures may not be accurate and are sometimes even exaggerated to attract media attention.
Floods	Increase in every region. Increase to more than trebled in Asia and to more than four-fold in Africa.	No particular regional trend except in Africa, where the numbers increased steadily.	
Windstorms	Increase in every region except for a trough during the period from 1995 to 1997 in Asia	No distinct trend,	
Slides	No distinct trends in any region except in Asia, where they increased more than four-fold.	Increase in Asia with a peak in the period 1995 to 1997. Steady decrease from 1988 in the Americas with a sharp increase in the early 1980s. In Europe, increase in the early 1980s, remained steady till the late 1990s, and then decreased.	
Droughts	No clear trend. In Africa, where droughts are prominent, droughts decreased in the period from 1992 to 1994, then increased again.	In Africa, increase till 1985, decrease till 1997, then increase again. In Asia, increase till 1991 and then sudden decline. More than 99% of the fatalities globally were reported in Africa.	
Water-borne epidemic diseases	Increasing trend, especially from the mid 1990s. Globally, the number of epidemics was at its highest in the period from 1998 to 2000, which is thought to be influenced by the African and Asian regional peaks.	Decrease in Asia but remained steady in Africa. Highest in the 1990s, when Africa, Asia and the Americas were all hit hard by epidemis. Since then decline in all three regions.	

Table 4-10: Risk, glacier outburst floods and management

PREVENTION		MANAGEMENT/MITIGATION		ADAPTATION
Risk identification	Flood Prevention	Property	Population	
Glacier lake inventory	Remote sensing of glaciers	Controlling lake drainage and dam stability	Developing a regional and local action plan	Re-locating hydropower facilities in non-threatened valleys
Identification of glaciers with history of GLOFs	Monitoring of glaciers and lakes	Reinforce natural dam or construction of artificial dam	Public Awareness and Education	Relocation of rural and urban settlements
GLOF hazard classification (probability of occurrence and magnitude)	Monitoring dam stability (ice or moraine)	Structural measures along channels	Evacuation plans/civil defence	Re-assessment of development projects
GLOF hydraulic modelling (hydrograph routing, sediment load)	Monitoring of triggering factors: temperature, glacial melting and calving instabilities, rock falls onto lakes, etc	Structures for lake water use	Health and safety regulations	
Hazard mapping and assessment of vulnerability of critical assets	Early warning system to villagers and managers of sensible infrastructure	Economic impact assessment (vulnerability and exposition)	Social impact assessment (vulnerability and exposition)	

Table 4-11: Links between sectors, exposure, vulnerability and impacts

Affected System/Sector	**Region [Resolution]**	**Examined period**	**Vulnerability (State of susceptibility and coping capacity)**	**Hazards/exposures and their extent**	**Impacts / Risks**	**Particularly severely affected groups (if exist)**	**Descripter of literature / Expected impacts**	**Reference(s)**
Food	Worldwide	-	-	Temperature	Impacts on crop production	-	Summary of effects of high temperature stresses on growth and development of various crops.	Hatfield et al. (2008)
Food	US, Japan	-	-	Temperature	Impacts on rice production	-	Summary of effects of high temperature stresss on growth and dvelopment of rice with a note on some threshold temperatures.	Kim et al. (1996); Prasad et al. (2006)
Food	Worldwide	-	-	Temperature	Impacts on maize production	-	Summary of effects of high temperature stresss on growth and dvelopment of maize with a note on some threshold temperatures.	Ben-Asher et al(2008); Fonseca and Westgate (2005)
Food	Whole Japan [4 sub-national regions]	Present (1981-2000), 2046-2065 and 2081-2100	Different levels of adaptation regarding planting date shift and heat tolerant variavirity use were assumed.	Temperature (daily maximum and minimum) , radiation, CO2 concentration	Rice yield (mean and inter-annual variability)	Tokai, Chubu, Kansai regions (Intensification of heat in summer is projected, which will cause decrease in and amplified inter-annual variability of rice yield)	Impact of climate change on rice yield in Japan was evaluated using the PRYSBI model, which explicitly simulates sterility and growth limitation due to extremely high and low temperature during yield formation period.	Yokozawa et al. (2009)
Food	Whole Japan (9 sub-national regions)	Present (1991-1999), 2071-2079	Change in standard rice yield (used for calculating insurance payouts) was permitted along with the change in rice yield.	Temperature (daily maximum and minimum) , daily total solar radiation, hourly maximum precipitation, hourly maximum wind velocity, and atmospheric CO2 concentration.	Rice insurance payouts (billion Japanese yen)	In Kanto-Tozan, Hokuriku, Kinki regions, the increase of 11-19% in rice insurance payouts is projected due to yield loss associated with heat stress.	Preliminary assessment of climate change impact on the rice insurance payout in Japan. Reflecting regional changes in yield, the rice insurance payout is expected to significantly decrease in northern Japan while it is expected to slightly increase in central and western Japan. In total, the 9-yr mean payout in Japan in the 2070s decreased to 120.2 billion yen (87% of the present payout averaged over 9-yr in the 1990s).	Iizumi et al. (2008)

Food	Andean region (Peru, Bolivia, Equador)	1970- current	-	Glacier retreat	Floods, water shortage (drought). GLOF, landslides.	Populations living in valleys depending from water from glaciers	With glaciers retreating due to global warming and El Niño episodes, the Andean region faces increasing threat on water supply. With most of the precipitation coming in 3-4 months, the glaciers plays a temporal buffer by stocking precipitations in ice and snow and redistribution of the water by melting during the dry season. The glaciers recession reduces the buffering role of the glaciers, hence inducing a double threat: more floods during raining season and more water shortage during the dry season. Physically, the glaciers are holding rocks and other debris. With retreating of glaciers, such debris are now exposed and could lead to debris flows after heavy rainfalls or after earthquakes. The recession of the glaciers also induces the formation of high altitude lakes and some of them include a risk of being suddenly released after earthquakes, of if an avalanche creates a GLOF. The risk of collapse of such dams can have drastic consequences.	Silverio and Jaquet (2005); Vuille et al. (2008); Zemp (2008)

Food	Global(Sub-national examples)	Now - near term future	The majority of households produce maize in many African countries, but only a modest proportion sell it – the great majority eat all they produce. In Kenya for example, nearly all households grow maize, but only 36% sell it, with 20% accounting for the majority of sales. This pattern sees a growing inequality of income which is likely to continue as farms get smaller due to population growth and environmental degradation (FAO, 2009). Both such famers and their governments have limited capacity for recovery (Easterling, W & Apps, M, 2005). Farmers do not usually have insurance although micro insurance is increasingly available.	Drought, floods, and cyclones are the main hazards faced by subsistence farmers. Rainfall pattern is also important. The economies of many developing countries rely heavily on agriculture; dominated by small-scale and subsistence farming. People's livelihoods in this sector are especially exposed to weather extremes (Easterling, W & Apps, M, 2005).	Food shortage and loss of cash livelihood due to crop failureCrop price increaseDegradation of food security	Subsistence farmers who have a marginal existence under normal conditions, are probably the most severely impacted by climate and weather events. The most vulnerable to food price increases are poor, urban residents in food-importing developing countries; the landless poor and female-headed households are also particularly vulnerable (FAO 2008). (Global food price increases are burdened disproportionally by low-income countries, where many people spend up to 50% of their income on food (OECD-FAO 2008)). In some locations women and girls bear the initial brunt of food scarcity, which is both a result of, and contributes to, systemic gender inequality (Vincent et al 2008).	The initial obvious impact is a shortage of food for those entirely dependent on their own produce for their food supply, and those whose cash livelihood depends on their own food crops. Crop-failure is a key driver for rural-urban migration, which is expected to be exacerbated under climate change. For example: Since 1970 Malawi has been facing increasing frequency and severity of drought and flood events, less seasonal rain and higher temperatures. A hybrid drought tolerant maize variety has been promoted, but requires expensive inputs such as chemical fertiliser, which is unaffordable for small holder farmers unable to find cash employment. These factors come together to create significant hardship for smallholder farmers (ActionAid, 2006). A more complex impact followed Cyclone Nargis in the Ayeyarwaddy delta region of Myanmar. The disaster's convergence with the global financial crisis has seen the rural economy collapse as credit has been withdrawn. Food security is again a significant concern (Stone, 2009). The factors influencing the recent price increases are in many ways a mirror to the challenges global food security will face in the next century under climate change. (Nelson et al (2009) Due to changes in marine ecosystems, populations will not be able to supplement their diet with fish, which is the primary source of protein for more than one billion people in Asia. Changes in rainfall patterns may disrupt major river systems used for irrigation. Rising sea levels could swamp fertile coastal land, rendering it useless. These impacts will be in conjunction with an increase in the frequency and severity of extreme weather events (Garnaut 2008).	ActionAid (2006); CGIAR (2002); Easterling and Apps (2005); Fischer et al (2005); FAO (2008); FAO (2009); Garnaut (2008); Nelson et al (2009) ; OECD-FAO (2008); Stone (2009)

Food	China	2000-2007	Less awareness and inadequte measures for the increasing climatic risks	Flood, Drought	Affected crop area	Northern China (drought); Yangtz and Huai river basins (flood)	25% loss of total annual crop production accounted for the flooding risk in China. Flooding disasters would have an increasing frequency and severity in future, especially in the major crop areas of Yangtz River basin and Huai Riverbasin. Northern China suffered from an expanding drought areas in recent 50 years (60% of annual average disaster-related crop loss caused by drought), and the trend would be worse in the next decade as well.	Commission for China's Climate Change Scientific Report
Food	China	2050	-	Temperature	Impacts on crop production	Middle and West of China.	China's total production of three major crops would reduce 5-10% at an average rate annually. Adaptive measures would lower down the vulnerability of these area.	Wang (2002)
Food	China	Near- mid term future	No adaptation assumed	Temperature	Impacts on crop production		an 2.5°C increase would cause a net decrease of Chinese crop production if without taking any adaptation measures.	Xiongwei et al, (2007)
Health	Lesotho, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe	Present (2001-2003)	High HIV/AIDS prevalence in modern area is causing high sensitivity to drought.	Drought	Child nutritional status (prevalence of underweight)	Better-off (modern) area with more HIV/AIDS	Areas with higher HIV/AIDS showed more deterioration in child nutrition. A significant area-level interaction was found of HIV/AIDS with the drought period, associated with particularly rapid deterioration in nutritional status. It is found that HIV/AIDS amplifies the effect of drought on nutrition, so rapid and effective response will be crucial when drought strikes.	Mason et la. (2005)
Health	North Indian Ocean (Bangladesh and Myanmar)	2007-2008	-	Tropical cyclones	Mortality	Coastal population in Bangladesh and Myanmar	Tropical cyclone Sidr (Bangladesh 2007) and Nargis (Myanmar 2008) are of similar intensity. However, the impacts (in mortality) were drastically different. By comparing these two events, the role of (good) governnance translated in improved early warning systems, preparedness and environment health, which mostly explained why Nargis had 32 times more casualties as compared with Sidr.	Gob (2008); Paul (2009); Webster (2008)
Health	Bangladesh	1991	Shelter	Cyclone	Mortality	Children <10 y.o. and 40+ yaers old females	Mortaliity was greatest among <10 years old children and 40+ years old females. Nearly 22% of persons who did not reach a concrete or brick structure died, whereas all persons who sought refuge in such structures survived.	Bern et al. (1993)
Health	Ethiopia	near past	a lack of flood-specific policy, absennce of risk assessment, and weak institutional capacity	Flood	deaths, injuries and diseases such as malaria and diarrhoea	-		Abaya et al. (2009)
Health	Bangladesh	1998	Lower education level, house with a non-concrete roof, tube-well water, distant water source and unsanitary toilets	Flood	Hospital visits due to diarrhoea (cholera and non-cholera)	Low SES group	In Dhaka, Bangladesh, the severe flood in 1998 caused diarrhea during and after the flood, and the risk of non-cholera diarrhea was higher for those with lower education level and not using tap water	Hashizume et al. (2008)

Health	Gernany	2002		Food	injuries and diarrhoea		In 2002 report, WHO assumed that countries with 6,000+ US dollars of per capita GDP. On the contrary, diarrhea as well as injuries occurred after a 2002 flood in Germany, one of the developed countries	Schnitzler et al. (2007)
Health	Mozambique	2000	Increase in population, food shortage, temporary living conditions, contaminated drinking water	Malaria and diarrhoea	Incidence		It may not always be true, but floods can increase the patients of malaria in some cases. In Mozambique, the incidence of malaria increased by 4 to 5 times after the flood in 2000 (compared with non-disaster periods)	Kondo et al. (2002)
water	China, Yellow Riiver	2030-2050	-		Water supply	Economic sectors	the Yellow River would have an increased annual cost of $ 500 million from 2030s to 2050s with a changing climate.	Kirshen et al. (2005)
Forestry / Ecosystem	The tropical forests of South America, Africa and Asia	1960 - current	-	Forest fires, drought, deforestation	Biodiversity losses, soil erosion, decication, GHG emissions, deforestation		Forest fires are increasing climate change by adding GHG into the atmosphere and by decreasing forest area for carbon sink. In turn, climate change induces more extreme events such as droughts and El Niño. Drought increases carbon emission from tropical forests by increasing forest flammability and tree mortality, and by suppressing tree growth. Droughts make peatlands more vulnerable to fires which contain vast amount of carbon. Drought is a trigger for human ignited forest fires leading to widespread deforestation and carbon emissions.	Field et al.(2009); Van Der Werf et al.(2008); Costa and Pires (2009); D'almeida et al. (2007); Phillips et al. (2009)
Forestry/ Ecosystem	North AmericaSiberia	-2100	-	Temperature	Forest fire (the area affected)		In western part of North America in the recent 30 years the area affected by forest fires increased twofold, and in the coming 100 years under expected warming it will further increase by 80%. Modelling of forest fires in Siberia shows that the temperature rise from 9,80C to 15,30C may result in the fact that a number of years with severe fires will increase twofold, an area affected by forest fires will be increasing by almost 15% per year and timber resources will reduce by 10%.	?
Forestry, tourism, ecosystems	Mediterranean countries (Portugal, Spain, Italy, Greece,…)	1900-2005 (observed) and 2020-2100 modelled	Increase duration of fire season and summer temperatures. Higher coping capacity by improving meteorological prediction, better forest fire fight resources, better knowledge of combustion material	Heat waves, droughts	Forest fires, lightning	Forest farming, tourism, rural settlements	?	?

Forestry / Ecosystem	China	1970-current	-	temperature, others	forest coverage		The economic loss of affected forests areas is more than 80 billion RMB annually since 1970s in China . The harmful insects affected forest is about 6% of total re-forestation in China annualy.	Yan and Cai (2006)
Housing, tourism, biodiversity, transport.	Coastal areas	current- 2100	-	Sea level rise			Coastal areas are among the world's most vulnerable to climate extremes, such as Sea Level Rise (SLR) and other events (e.g. tropical storms and cyclones and related storm surges), the intensity and frequency of which is projected to increase. Moreover, as the size/permanence of coastal communities and infrastructure has increased very significantly over recent decades, affecting the ability of coastal systems to respond effectively to SLR and other extreme climate events, the exposure of coastal communities/assets is growing at an ever increasing rate. The severity of the impacts will depend on the rate of SLR, with rapid SLR likely to impact more severely natural systems and amplify the potential economic losses/costs of adaptation. Coastal landforms (beaches, seacliffs, estuaries, lagoons, deltas) are highly likely to suffer increased rates of erosion, while coastal ecosystems, such as coastal wetlands, coral reefs and seagrasses may also be severely affected. Economic activities in coastal areas that may be at threat from SLR and other extreme events include among others transportation (ports and other coastal infrastructure, e.g. airports, railways and roads) and tourism (due to beach erosion and threat to coastal tourism infrastructure). Small island states, particularly SIDS, are likely to be very severely affected; in some cases, and depending on the SLR scenarios, there might even be a need for permanent population evacuation. In some coastal settings and landforms (e.g. deltas and coastal wetlands), SLR will be further exacerbated by (i) land subsidence triggered by natural processes (e.g. sediment auto-compaction) and/or human-induced interference (e.g. extraction of groundwater/hydrocarbons); (ii) diminishing sediment supply due e.g. to river damming and other management schemes.	The Copenhagen Diagnosis (2009); Lenton et al(2009); Cai et al.(2009); Ericson et al. (2006); Woodroffe (2008)
Settlements	Russian arctic		-	Permafrost degradation	Damage on foundations of buildings Disruption of operation of vital infrastructure in human settlements		Climate warming leads to permafrost degradation, the 40-80-cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost [Sherstyukov, 2009]. Changes in permafrost damage the foundations of buildings and disrupt the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10-12% in 20-25 years, with permafrost	Sherstyukov (2009); Anisimov et al. (2004)

							borders moving 150-200 km northeast [Anisimov et al., 2004].	
Infrastructure / Settlements	Whole Japan [1kmx1km]	Present (1970-2000), Around 2050	Exposed economic value is estimated for each grid with using spatial land-use data and unit values of the land-use classes.Assuming the status quo for future.	Landslide exacerbated by increasing intensity of precipitation.Exposed economic value of each grid cell is assumed not to change (the status quo).	Economic loss due to landslide	Area with high expected economic loss due to landslide concentrate in some prefectures (Tochigi, Gumma, Saitama, Toyama, Ishikawa, Fukui, Hiroshima, Kagoshima).	Slope failure risk is expected to increase in future at many places, since increase in frequency/intensity of strong rainfall is projected by climate models. Slope failure risk in Japan under the changed precipitation was evaluated for the period around 2050 with spatial resolution of 1km^2. With using spatial data on daily precipitation, geography, geology, and landuse, slope failure probability in each grid cell was calculated first. Then, with multiplying economic value of each grid cell, expected economic loss due to slope failure (return period: 50 years) under the changed climate condition was calculated. For creating daily precipitation sceario in future, climate projections of MIROC3.2-hires (AO-GCM with 1.125x1.125 resolution) and MRI-RCM20 Ver.2 (Dynamical downscaling using RCM with 20kmx20km resolution) were employed. Grid cells with high slope failure risk is expected to distribute from the top to the skirts of mountainious area. Especially, in the south Hokkaido region, the coast of Japan Sea from Hokuriku region to Chugoku region, and median tectonic zone from Tokai region through Shikoku region, incrase in slope failure risk is most significant. In some prefectures (Tochigi, Gumma, Saitama, Toyaam, Ishikawa, Fukui, Hiroshima, and Kagoshima), area with high expected economic loss due to slope failure concentrates. Therefore, prioritized implementation of adaptation measures will be needed in those prefectures.	Kawagoe and Kazama (2009)

Settlements/other	Global	Current – short term	Most urban centres in sub-Saharan Africa and in Asia have no sewers (Hardoy, Mitlin and Satterthwaite, 2001). Sanitation infrastructure is the main determinant of the contamination of urban floodwater with faecal material, presenting a substantial threat of enteric disease (Ahern et al., 2005). In Andhra Pradesh, India, a heat wave killed more than 1,000 people – mostly labourers working outside in high temperatures in smaller urban settlements (Revi, 2008).	Flooding (also leading to disease), landslides (UN/POP/EGM-URB/2008/16) Heatwaves (Kovats and Aktar 2008). It is well documented that, in most cities, the urban poor live in the most hazardous urban environments – for instance on floodplains or other areas at high risk of flooding or unstable slopes (Hardoy, Mitlin and Satterthwaite, 2001). Worldwide, about one billion live in informal settlements, and this proportion is growing at about twice the rate of formal settlements.		A large proportion of those in informal settlements are especially susceptible to harm with limited ability to recover. Groups especially impacted include infants and older groups who are less able to cope with heat waves, and less able to escape floodwaters. Those who work outside without heat protection are also very vulnerable (UN/POP/EGM-URB/2008/16)	Climate change is likely to bring ever-increasing numbers of accidental deaths and serious injuries and increasingly serious damages to people's livelihoods, property, environmental quality and future prosperity – especially the urban poor in informal settlements (UN/POP/EGM-URB/2008/16). Poorer groups get hit hardest by this combination of greater exposure to hazards (e.g., a high proportion living on unsafe sites) with no or limited hazard-removing infrastructure, and high vulnerability due to makeshift housing with less capacity to cope due to a lack of assets, insurance, and marginal livelihoods, with less state support and limited legal protection. Low-income groups also have far less scope to move to less dangerous sites (UN/POP/EGM-URB/2008/16). Informal settlements are found in all regions, for example there are some 50 million people in such areas in Europe (UNECE 2009).	Ahern et al.(2005); Douglas et al.l (2008); Hardoy et al.(2001); Kovats and Akhtar (2008); Revi (2008); UNECE (2009)

Energy	Iberian Peninsula, Mediterranean regions	1920–2000	Hydroelectric productionrepresents, in an average year of precipitation, 20% of the total Spanish electricity production and 35% for Portuguese production. Other renewal energy sectors are being developed, mainly windpower and solar energy.	Low precipitation, Drought	Decrease in hydropower production	Economic sectors	Throughout most of the 20th century, North Atlantic oscillation (NAO) correlates with winter precipitation and river flow regimes for the three main international Iberian river basins, namely the Douro (north), the Tejo (centre) and the Guadiana (south). The impact of the NAO on winter river flow was quantified in terms of total Spanish potential hydroelectricity production. The important control exerted by the NAO and the recent positive trend in the NAO index contribute to a significant decrease in the available flow, and therefore, hydropower production in the Iberian Peninsula	Trigo et al., 2004

Tourism	Global	Current – short term	Most tourist enterprises are subject to weather conditions and are susceptible to harm from changes unless the changes are beneficial which may happen in some areas. Capacity to recover is likely to depend on teh degree of dependence on tourism with diversified economies being more robust. Low lying coastal areas and areas currently on the edge of the snow line may have limited alternatives. Some resorts will be able to adapt using snow machines, but some will fail (Elsasser & Bürki, 2002).	Heatwaves, cyclones, coastal erosion, disease outbreaks associated with changed climate. See impacts for detailed examples. Approximately 10% of global GDP is spent on recreation and tourism (Berrittella et al, 2005). The distribution of global tourism is expected to shift polewards due to increased temperatures associated with climate change. Parts of the Mediterranean, a very popular summer tourist spot, may become too hot in summer but more appealing in spring and autumn. More temperate tourist destinations are predicted to become more attractive in summer. Tourist seasons in different areas are expected to shift, with sem areas gaining whiel others lose (Amelung et al, 2007; Bigano et al, 2007).		Small island states are often dependent on tourism, and the tourism infrastructure that lies on the coast is threatened by climate change. The aviation industry is currently subject to very low or no taxes on greenhouse emissions. If an international carbon-pricing agreement were reached, this could have detrimental impacts on tourism globally, particularly following a period of historically low airfares (Amelung & Viner, 2006).	The main impact will be decline in revenue from tourism, with loss of livelihoods for those working in the sector.Tropics: Increase cyclone intensity, with wind speeds expected to increase up to 20% (Preston et al, 2006; World Bank, 2000). In the Caribbean, reduced tourist amenity as beaches erode with sea level rise, and degraded snorkelling and scuba activities due to coral bleaching (Uyarra et al, 2005).Alpine: heatwaves and rising temperatures raising the snow line. In Switzerland only 44% of ski resorts will be above the 'snow-reliable' altitude by approximately 2030, as opposed to 85% today (Elsasser & Bürki, 2002).Disease: Ross River fever outbreaks in Cairns, Australia, have a significant impact on the local tourist industry. The conditions for an outbreak such as increased temperatures and humidity are predicted to increase under climate change (Tong & Hu, 2001). Calgaro & Lloyd (2008) argue that political and economic incentives exist to suppress information about the coastal hazards in an effort to attract tourism, and that this cost both lives and livelihoods in Khao Lak.The aviation industry is currently subject to very low or no taxes on greenhouse emissions. If an international carbon-pricing agreement were reached, this could have detrimental impacts on tourism globally, particularly following a period of historically low airfares (Amelung & Viner, 2006).	Amelung et al (2007); Amelung & Viner (2006) ; Berrittella et al (2006); Bigano et al (2007); Calgaro & Lloyd (2008); Elsasser & Bürki (2002); Preston, B et al (2006); ; Tong & Hu (2001); Uyarra et al (2005); World Bank (2000)
Tourism	Mediterranean countries	Present	High in coastal areas and snow-related tourism	High summer temperatures, Heat waves (tropical nights), droughts	Decrease in number of tourist, change of tourism season	Tourist local services, travel-related industry	Change on the tourist behaviour, decreasing the stay period, delaying the travel decision, changing the selection of destination. Increase on travelling and holidays during transition seasons (spring and autumn)	Perry (2003); Esteban Talaya et al. (2005)

Tourism	world, regional	Near term	-	climtatic variation	tourism demand		Variations in tourist flows will affect regional economies in a way that is directly related to the sign and magnitude of flow variations. At a global scale, climate change will ultimately lead to a welfare loss, unevenly spread across regions.	Berrittella et al.(2006)
Tourism	EU countries	Near past	-	climate	tourist destination		For European countries during the summer months, there would be an increase in attractiveness; however, the northern European countries become relatively more attractive closing the gap on the currently popular southern European countries.	Hamilton (2003)
Economy (insurance)	US, Japan, Europe	Long-term (2080s)	No change (Assuming the status quo for future)	Change in windstorm characteristics. All exposure information (location and density of population and property, physical characteristics of the property, asset values) was kept constant at today's values.	Annual average insured loss Insured loss with chance of occurring once every 100 years Insured loss with chance of occurring once every 250 years	-	This study focuses on one of the most costly aspects of today's weather – hurricanes, typhoons, and windstorms, because of their potential to cause substantial damage to property and infrastructure. Annual losses from the three major storm types affecting insurance markets (US hurricanes, Japanese typhoons and European windstorms) could increase by two-thirds to $27 bn by the 2080s. Focussing on the most extreme storms (losses occurring once every 100 to 250 years), by the 2080s climate change could: • Increase wind-related insured losses from extreme US hurricanes by around three-quarters to total $100 – 150 bn. • Increase wind-related insured losses from extreme Japanese typhoons by around two thirds to total $25 – 34 bn (¥2,700 – 3,700 bn). • Increase wind-related insured losses from extreme European storms by at least 5% to $32 – 38 bn (€25 – 30 bn).	ABI (2005)
Economy	Indonesia	Current	-	flooding	Food shortage, water and soon	Economic sectors,health, community,et al	Climate change threatens to undermine Indonesia's efforts to combat poverty.Livelihoods – The effects of climate change are being felt more acutely by the poorest communities.Health –Heavy rainfall and flooding can overwhelm rudimentary systems of sanitation in slum areas of towns and cities,exposing people to water-borne diseases such as diarrhoea and cholera.Food security – The poorest regions are also likely to suffer food shortages.Water – Changing rainfall patterns are also reducing the availability of water for irrigation and for drinking.	UNDP (2007)
Climate system	Tropical forests	1960-current	-	Extreme deforestation	Change in precipitations patterns		A drastic deforestation scenario would result in a severe restructuring of land–atmosphere dynamics, partially explaining why most AGCMs have predicted weakened water fluxes as a result of extensive deforestation. A basin-wide deforestation scenario would impose a severe decline on evapotranspiration and then on precipitation recycling, weakening the hydrological cycle in Amazonia as a whole.	D'almeida et al.(2007)

Others	Viet Nam	2009	-	disasters, food shortage,health, et al	employment, health ,livelihood,working of women	gender equality	The poor,women and children are among the most vulnerable to climate change effects, and climate change may in fact worsen gender inequalities, create extra work for women,and exacerbate vulnerability of women in poor households. Yet gender has to date been relatively neglected in research and policy analysis, as well as in international and national policy processes.	Oxfam and UNDP (2009)

Table 4-12: Impact of climate change by 2071-2100 on flood risk in Europe (Ciscar, 2008). Note that the numbers assume no change in population or development in flood-prone areas

Region	B2: HadAM3h (2.5°C)	A2: HadAM3h (3.9°C)	B2: ECHAM4 (4.1°C)	A2: ECHAM4 (5,4°C)	1961-1990
Additional expected population affected (1000s/year)					Baseline
Northern Europe	-2	9	-4	-3	7
British Isles	12	48	43	79	13
Central Europe (north)	103	110	119	198	73
Central Europe (south)	117	101	84	125	65
Southern Europe	46	49	9	-4	36
EU	276	318	251	396	194
Additional expected economic damage (million €/year, 2006 prices)					Baseline
Northern Europe	-325	20	-100	-95	578
British Isles	755	2854	2778	4966	806
Central Europe (north)	1497	2201	3006	5327	1555
Central Europe (south)	3495	4272	2876	4928	2238
Southern Europe	2306	2122	291	-95	1224
EU	7728	11469	8852	15032	6402

Table 4-13: Identification of extreme impacts affecting the tourism sector by regions. Sources: IPCC 2007; Ehmer and Heymann, 2008; Scott et al., 2008]

Regions/ subregions	Tourism value exposed to hazard	Sub-sectors vulnerability	Potential extreme impacts
Mediterranean countries	- Tourism highly dependent on climate - Contribution of GDP: Spain (17%), Portugal (14%), France (9%), Italy (9%), Greece (16%); Turkey (11%), Croatia (17%), Morocco (16%), Tunisia (17%)	- Summer exceeding comfortable temperature levels highly vulnerable in Spain, Portugal, Greece, Turkey and islands (Malta, Cyprus) -Cultural and city holidays unaffected -Ski resorts outside glaciers highly vulnerable. Lack of flexibility of snow touristic destinations	- Heat waves, days exceeding 40ºC and tropical nights - Droughts, and water shortage - Lack of snow, water demand for artificial snow production - Increase risk of forest fires - Return of diseases (e.g. malaria) cannot be ruled out - More frequent flooding affecting new urbanized areas - More intense coastal storms (beach erosion)
Central Europe	- Tourism slightly dependent on climate - Contribution of GDP: Germany (8%), Benelux countries (8%), UK (4%), Ireland (4%), Austria (15%), Switzerland (13%)	- Positive effects for activity holidays on northern coastal areas - City tourism (15%) unaffected - Heath resorts non affected - Ski tourism with a shorter season in Alps. - Higher-lying winter sports resorts may escape adverse snow conditions.	- Longer summer season - Heat waves to increase in countries no adapted to high temperatures. - Summer floods in central European rivers and southern UK - Lack of snow in the low elevation ski resorts during winter: - High risk of coastal erosion to affect Britain coastal resorts. - Rising sea level and the risk of flooding in low lands of The Netherlands.
Northern Europe	- Tourism seasonal non dependent on climate - Contribution of GDP: Denmark (8%), Sweden (6%), Norway (7%),	- Positive effects for seaside summer holidays, particularly in Denmark and Sweden - Tourism emphasis on nature to increase due to longer season - Reliable snow cover will be maintained (at	- Extended summer season - Winter snow conditions may be deteriorated at low altitudes but improved during winter due to increased snow precipitation amount.

	Findland (8%), (15%), (13%)	least until 2050s)	
Eastern Europe	- Tourism non dependent on climate - Contribution of GDP: Estonia (14%), Slovakia (13%), Czech Republic (12%), Bulgaria (12%), Slovenia (12%), Ukraine (8%), Hungary (7%), Poland (7%), Lithuania (7%), Russia (6%), Romania (5%), Latvia (4%)	- Cultural tourism less sensitive to climate change - Countries bordering Black Sea may benefit from climate impacts in nearby regions - Decrease lake levels may interfere with water sports - Summer convalescence and health tourism is no vulnerable to climate impacts. - Winter sport tourism to face problems by 2030s	- Droughts and higher evaporation to affect lake resorts and mountain landscapes - Decreasing duration of snow season
Caribbean	- Tourism highly dependent on climate. Contribution of GDP: Puerto Rico (6%), Cuba (7%), Dominican Republic (14%), Jamaica (33%), Bahamas (51%)	- None effect of temperature rise - Major impacts from weather extremes in high vulnerable economies - Increasing incidence of vector-borne diseases	- Tropical storms to increase - Water shortage - Coastal erosion by storms - Coral bleaching - Loss of biodiversity
North America	- Tourism slightly dependent on climate - Contribution of GDP: USA (9%), Canada (10%),	- Positive effects on nature and adventure tourism. - Skii in Rocky Mountains less severely affected than Alps.	- Extended summer season - Increase in hurricane intensity in SE USA. - Droughts and forest fires in SW USA
Latin America	- Tourism slightly dependent on climate - Contribution of GDP: Mexico (13%),	- Tours to landscape and cultural factors (Maya ruins, Machu Picchu) slight climate dependence - Rising temperatures and natural disaster to	- Rising temperatures and heat waves. - Droughts and water shortage - More intense tropical storms to cause damage of infrastructures

	Argentina (6%), Brazil (5%)	affect negatively in tourist comfort at seaside resorts. - Increasing incidence of vector-borne diseases	
Asia	- Tourism highly dependent on climate - Contribution of GDP Indonesia (6%), Thailand (13%), Philippines (6%), Sri Lanka (8%), Malaysia (12%), India (4%)	- Cultural and landscape tourism popular in Asia is less climate-sensitive - Sea side resorts negatively affected by rising temperatures - Increasing incidence of vector-borne diseases - Philippines highly vulnerable to increase weather extremes - Tourism sector to remain a growing sector despite of climate change	- Coral bleaching to reduce attractiveness of diving regions (eg. Bali) - Increasing problems of water supply - Floods during monsoon season can be worsen. - Landslides in steep mountain areas - Higher severity of cyclones to produce high damage and socio-economic disruption - Coastal erosion to increase (e.g. India and Asian delta areas)
Island states	- Tourism highly dependent on climate - Contribution of GDP Maldives (58%), Seychelles (55%), Mauritius (24%)	- Loss of biodiversity and coral bleaching may affect diving tourism. - Sea level rise to affect low-lying Maldives archipelago	- Possible reduction of precipitation with subsequent water supply problems - Coral bleaching
Africa	- Tourism highly dependent on climate - Contribution of GDP Tanzania (%), Kenya, South Africa	- Loss of biodiversity and desertification. Infrastructure protected by naturally vegetated coastal dunes, were better protected than those with sea walls (e.g. Natal coast of South Africa). - Loss of natural resources for wildlife - South Africa is the less climate-	- Droughts and increase aridity - Flooding and heavy rainfall to increase - Water shortage - Extreme wind events (cyclones) and storm surges leading to structural damage and shoreline erosion in Mozambique.

		dependent country - Increasing incidence of vector-borne diseases	
Australia/ Oceania	- Tourism slightly dependent on climate - Contribution of GDP Australia (11%), New Zealand (11%), Pacific Islands	- City tourism non-sensitive to climate impacts - Australian outback tourism to seasonal readjusts to avoid high temperatures - Australia: Tourism activity to be centered during austral winter - Adventure holidays and green holidays to benefit in New Zealand	- Coral bleaching to affect attrativeness of the Great Barrier Reef - Queensland region subject to flooding - Droughts and water shortages to increase in Australia - Forest fires to increase in New South Wales - Sea level rise derived problems to affect South Seas archipelagos and Polynesia
Middle East	- Tourism highly dependent on climate - Contribution of GDP Egypt(%), United Arab Emirates (%)	- Loss of comfort resulting from rising temperatures in summer months - Winter tourism to increase. Seaside tourists to avoid summer months. - Cultural tourism less susceptible to climate impacts	- High temperatures and heat waves - Water shortage - Coral bleaching to affect Read Sea reefs

Table 4-14: Summary of climate extremes in Europe – hazard, exposure, vulnerability, and impacts.

Climate extreme	Changes in hazard	Exposure	Vulnerability	Impacts
Heat wave	Increase in frequency and severity (observed and projected)	Ageing society. Prevailing urban population	Old, sick, and lonely suffer most. Conditions for summer tourism industry in the south deteriorate	Tens of thousands of additional deaths during the heat wave in summer of 2003. Heat-related deaths likely to increase
Cold wave	Decrease in frequency and severity (observed and projected)	Throughout most of Europe	Homeless, people under influence of alcohol	Despite the warming, during some of winters in 2000s, cold waves kill hundreds. Adverse effects of warmer winters in agriculture (pest thrive)
Intense precipitation, river flood, landslide	Increase in mean precipitation intensity observed and projected. No ubiquitous increase of annual maximum river flow observed. Large changes in flood risk are projected (see Fig. X), but uncertainty in projections is considerable	Population of flood-prone and slide-prone areas	Uninsured / uninsurable households	Summer 2002 flood resulted in material damage of 20 billion Euro. Over much of the continent, a 100-year flood in the control period will be more frequent in the future.
Drought	No robust change of drought properties observed. Projections of increasing frequency and severity of summer droughts over much of Europe	Throughout the continent	Particularly adverse effects in the south	Drought of summer 2003 resulted in multi-billion material damage
Wild fire	Often accompanying heat wave and drought (on the rise). Increase in Fire Weather Index is projected.	Throughout the continent	Semi-arid areas of Southern Europe. Pine forests (largely monocultures) in Central Europe	Large, and destructive, wild fires in 1992 (Central Europe), 2003 (Southern Europe), and 2007 (Greece). In the Mediterranean over 0.5 million ha has burnt annually

Gale wind	Some increase in extreme wind speeds in parts of Europe (observations and projections), but low confidence in projections	Infrastructure, forests. Increase of total growing stock in forest	Light-weight roofs, pylons of transmission lines. Age class and tree species distribution in forests. Conifers are more vulnerable to wind damage than broadleaved species	Very high material and environmental damage, e.g. of the order or 10 billion Euro in December 1999 (storms: Anatol, Lothar, Martin). On 8 Jan 2005, the Erwin (Gudrun) storm over 75 million m^3 of windfall timber damage in Southern Sweden
Coastal flooding	Increase in storm surges accompanying sea-level rise	Increasing number of population inhabiting European coasts	Cliff coasts, low-lying coasts	Projections show increasing number of people suffering from coastal flooding (Fig. X)
Snow deficit	More frequent and more severe (observed and projected)	Winter tourism industry	Lower-elevation stations	Considerable reduction of the number of skiing days

Table 4-15: Climate extremes, vulnerability and impacts

Climate Extreme	Changes in Climate Extremes	Exposure	**Vulnerability**	**Impacts**
Tropical Cyclones	Possibly lower frequency but increasing magnitude	Very high for atolls and coastal communities. High for most countries. Low for PNG Highlands, Nauru and Kiribati (too close to equator).	Reduction of traditional coping measures.	Greater levels of mortality, injury and hardship. Housing agriculture and infrastructure damage
• Wind	Increased wind speeds (?)	Houses, some food crops, tree crops, electricity and communications lines	Expansion of coconut as a commercial crop and tapioca as an alternative to traditional staples such as taro and yams. Transitional housing and squatter settlements.	Destruction of homes, loss of food security, disruption of commercial livelihoods. Destruction/damage to infrastructure
• Rain	Increased rainfall intensities	See intense rainfall events	See intense rainfall events	
• Storm Surge	Increased storm surge heights, exacerbated by sea level rise and coral reef degradation	Coastal areas of all islands and atolls. Ghyben-Herzberg lens of atolls exposed to salinisation	Urban growth (most towns are coastal). Tourism development.	Damage to coastal communities (housing, infrastructure, crops), Salinisation of Gyben-Herzberg lens on atolls
Intense Rainfall Events	Increased rainfall intensities			
• River Flooding	Increased flood events	Large inter-plate islands with well developed river systems and flood plains as well as deltas, both heavily populated. Flash floods on volcanic high islands with small catchments.	Watershed deforestation, increasing population densities	Destruction/damage to settlements and crops, to infrastructure (roads and bridges).
• Land/mud slides	Increased land/mud slide events	Locations at the base of slopes	Increased through deforestation	Destruction/damage to settlements and crops, to infrastructure (roads and bridges).
Drought	Increased frequency and magnitude (duration, severity of rainfall decrease) of drought events	Throughout region, especially atolls, PNG Highlands	Increasing density urban population densities, especially in atoll countries	Reduced water quantity and quality, health problems, reduce agricultural productivity

Frost (PNG Highlands)	Reduction in occurrence? But droughts may increase in magnitude and frequency	Papua New Guinea Highlands	Traditional responses reduced by relief programmes	?
King tides and high wave events	Exacerbated by sea level rise	Low lying coastal areas and atolls	Urban growth (most towns are coastal). Tourism development.	Salinisation of Ghyben-Herzberg lens on atolls, coastal flooding.
Tsunami	Non climate but exacerbated by sea level rise and coral reef degradation	Low lying coastal areas and atolls	Urban growth (most towns are coastal). Tourism development.	Destruction of buildings, infrastructure and crops at elevations higher than would otherwise be the case.

Table 4-16: Pacific Island type and exposure to risks arising from climate change

Island Type	Exposure to climate risks
Plate-Boundary Islands	
Large High elevations High biodiversity Well developed soils River flood plains Orographic rainfall	Located in the western Pacific these islands are exposed to droughts. River flooding is more likely to be a problem than in other island types. Exposed to cyclones, which cause damage to coastal areas and catchments. In PNG high elevations expose areas to frost (extreme during El Nino), however highlands in PNG are free from tropical cyclones. Coral reefs are exposed to bleaching events. Most major settlements are on the coast and exposed to storm damage and sea-level rise.
Intra-Plate (Oceanic) Islands **Volcanic High Islands**	
Steep slopes Different stages of erosion Barrier reefs Relatively small land area Less well developed river systems Orographic rainfall	Because of size few areas are not exposed to tropical cyclones, which cause most damage in coastal areas and catchments. Streams and rivers are subject to flash flooding. Most islands are exposed to drought. Barrier reefs may ameliorate storm surge and tsunami. Coastal areas are the most densely populated and exposed to storm damage and sea level rise. Localised freshwater scarcity is possible in dry spells. Coral reefs are exposed to bleaching events.
Atolls	
Very small land areas Very low elevations No or minimal soil Small islets surround a lagoon Shore platform on windward side Larger islets on windward side No surface (fresh) water Ghyben Herzberg (freshwater) lens Convectional rainfall	Exposed to storm surge, ‘king’ tides and high waves, although exposure to cyclones is much less frequent than in islands to the west and south. Flooding arises from high sea-level episodes. Exposed to fresh water shortages and drought. Fresh water limitations may lead to health problems. Coral reefs are exposed to bleaching events. All settlements are highly exposed to sea-level rise.
Raised Limestone Islands	
Steep outer slopes Concave inner basin Sharp karst topography Narrow coastal plains No surface water No or minimal soil	Depending on height may be exposed to storm surges and wave damage during cyclones and storms. Exposed to fresh water shortages and drought. Fresh water problems may lead to health problems. Flooding is extremely rare. Coral reefs are exposed to bleaching events. Settlements are not exposed to sea-level rise.

Source: Campbell (2006)

Table 4-17: Climate related disaster occurrence and regional average impacts from 2000-2008
Sources: Vos F, Rodriguez J, Below R, Guha-Sapir D. *Annual Disaster Statistical Review 2009: The Numbers and Trends*. Brussels: CRED; 2010. page 5-7, page25.

Sub group of disasters (type)		Africa	Americas	Asia	Europe	Oceania	Global
Climatological (storm)	No. of Disasters	*9*	*13*	*13*	*17*	*1*	*54*
	Damages (2009 US$ bn)	*0.05*	*2.36*	*3.47*	*3.15*	*0.36*	*9.39*
Meteorological (Extreme Temperature, Drought, Wildfire)	No. of Disasters	*9*	*35*	*42*	*15*	*7*	*108*
	Damages (2009 US$ bn)	*0.08*	*39.93*	*10.30*	*3.01*	*0.31*	*53.63*
Hydrological (flood, land slides, etc)	No. of Disasters	*42*	*39*	*81*	*26*	*5*	*194*
	Damages (2009 US$ bn)	*0.37*	*2.99*	*9.05*	*7.01*	*0.52*	*19.94*
Total average	No. of Disasters	*60*	*87*	*136*	*58*	*13*	*356*
	Damages (2009 US$ bn)	*0.50*	*45.28*	*22.82*	*13.17*	*1.19*	*82.96*

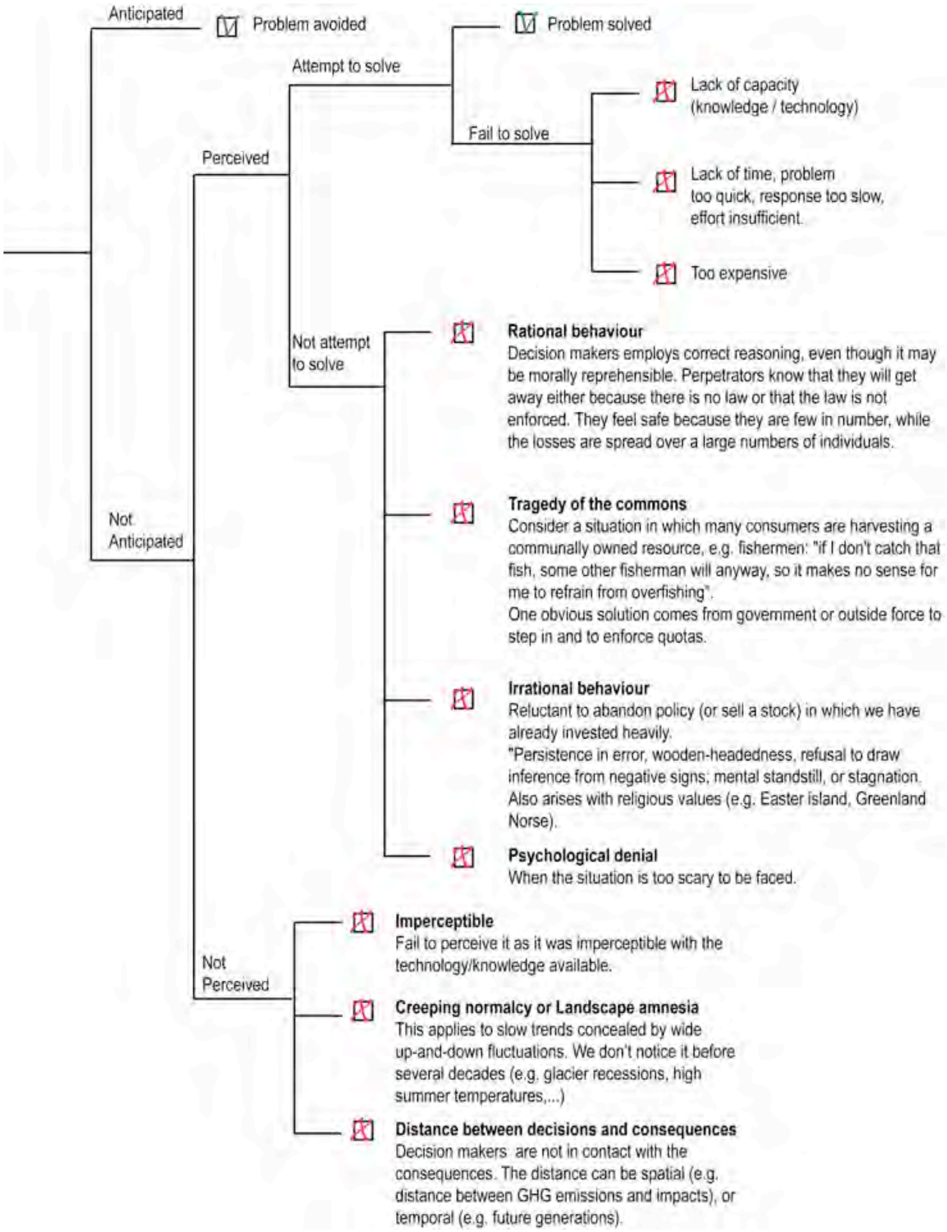


Figure 4-1: A path model to societal success or failure
Schema based on Diamond (2005), pp. 419-440.

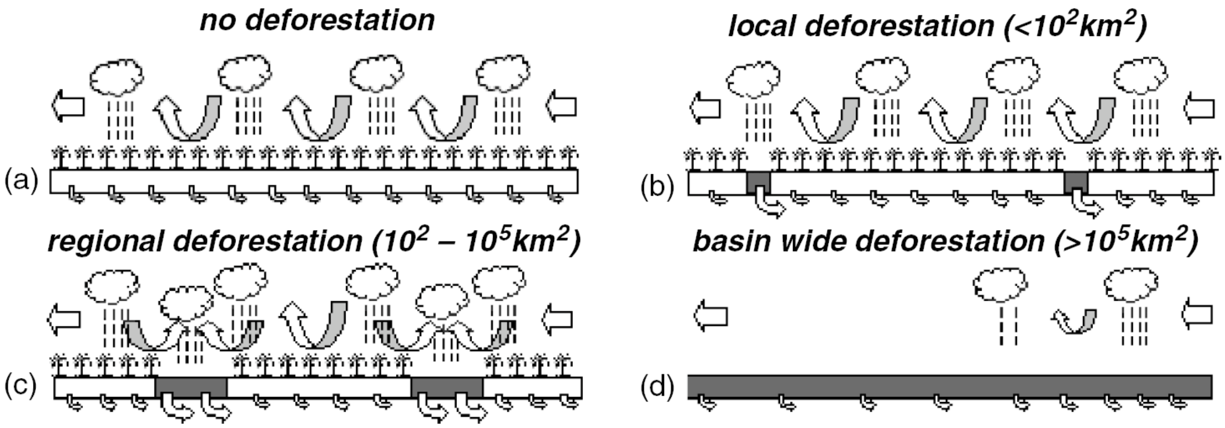


Figure 4-2: Tropical forest fires. Schematic representation of the hydrological impact of different extents of clearing (in dark gray) in Amazonia. The horizontal water vapor flux transfers moisture into the region and in the case of (a) no deforestation, this flux is sustained by precipitation recycling, maintaining high indices of rainfall. Areas of (b) local deforestation are too small to affect rainfall, but runoff increases and evapotranspitation decreases. Areas of (c) regional deforestation are large enough to influence circulation, strengthening convection and potentially increasing rainfall. A (d) basin-wide deforestation scenario would impose a severe decline on evapotranspiration and then on precipitation recycling, weakening the hydrological cycle in Amazonia as a whole. Sources: (D'Almeida et al., 2007)

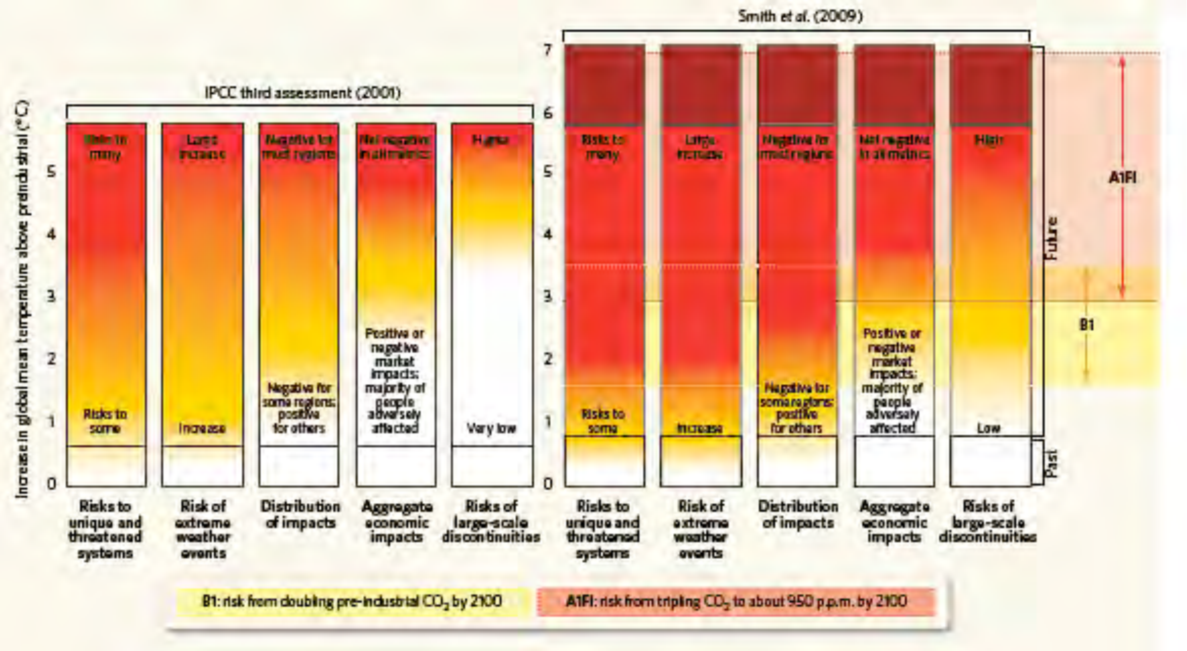


Figure 4-3: Burning embers. Source: Schneider, 2009

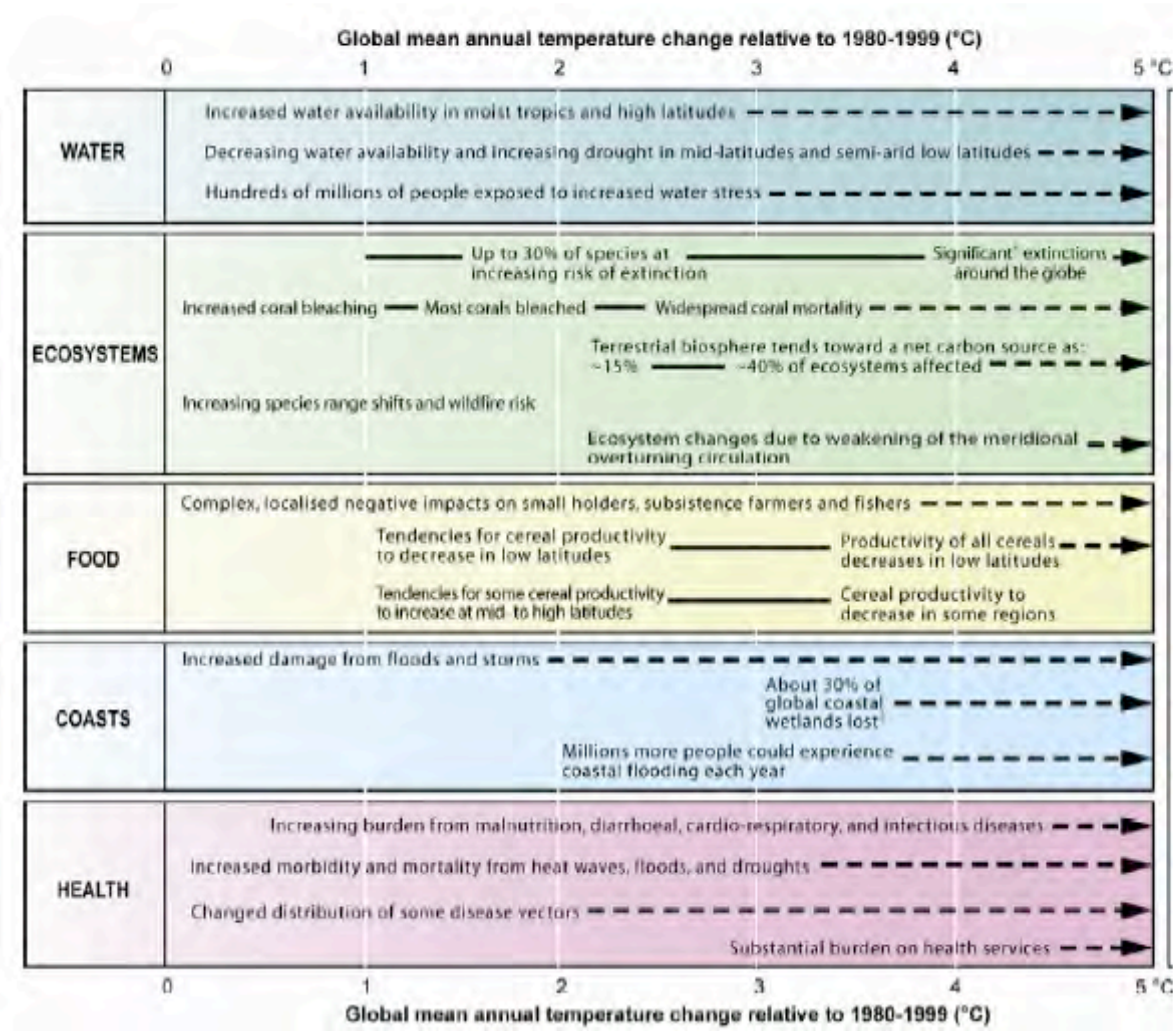


Figure 4-4: Global impacts of climate change.

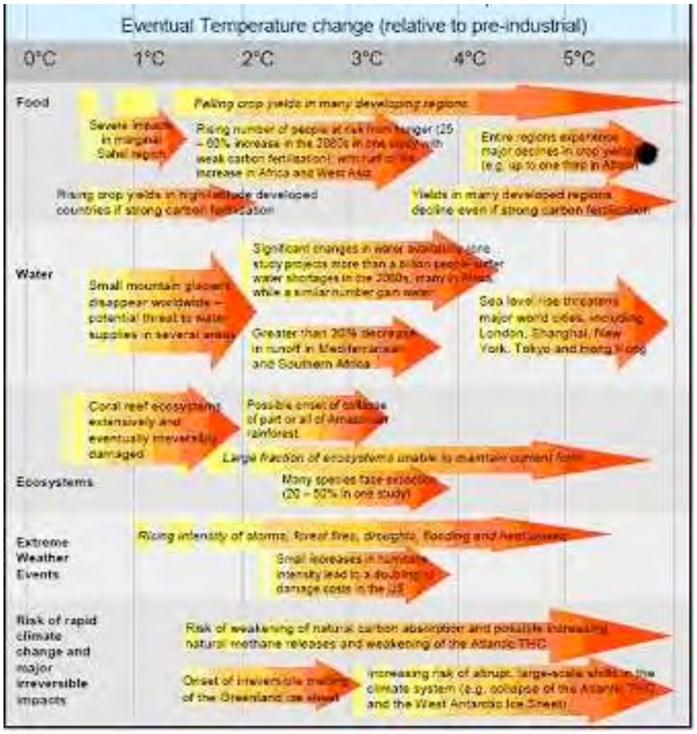


Figure 4-5: Illustrative examples of global impacts projected for climate changes.
Source: Stern (2006).

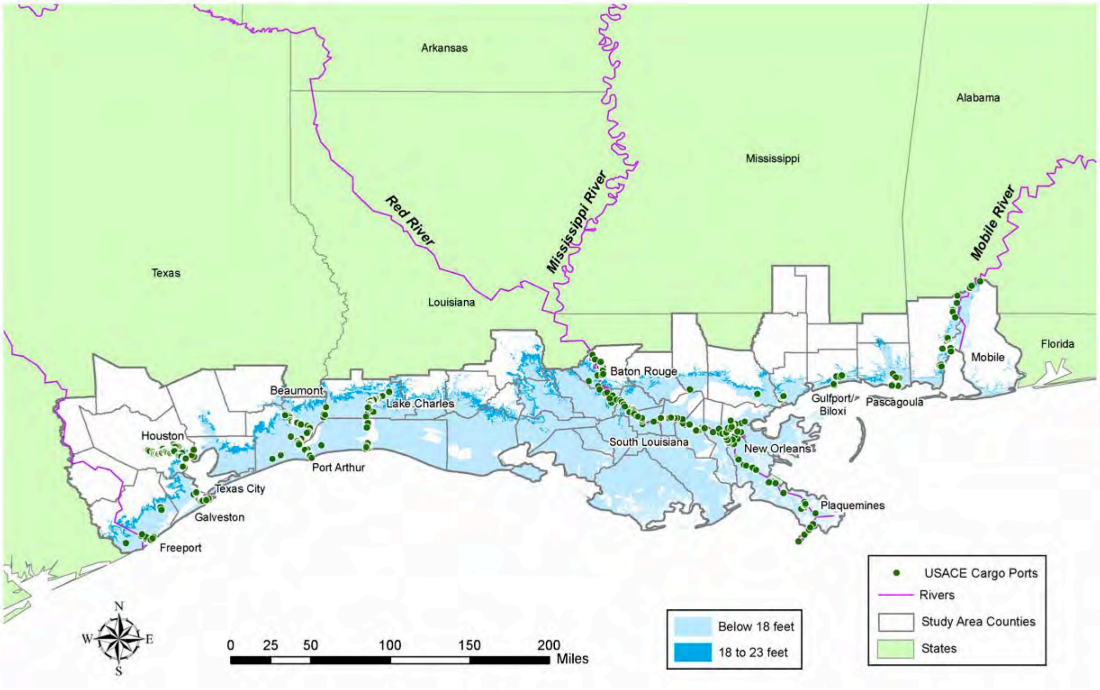
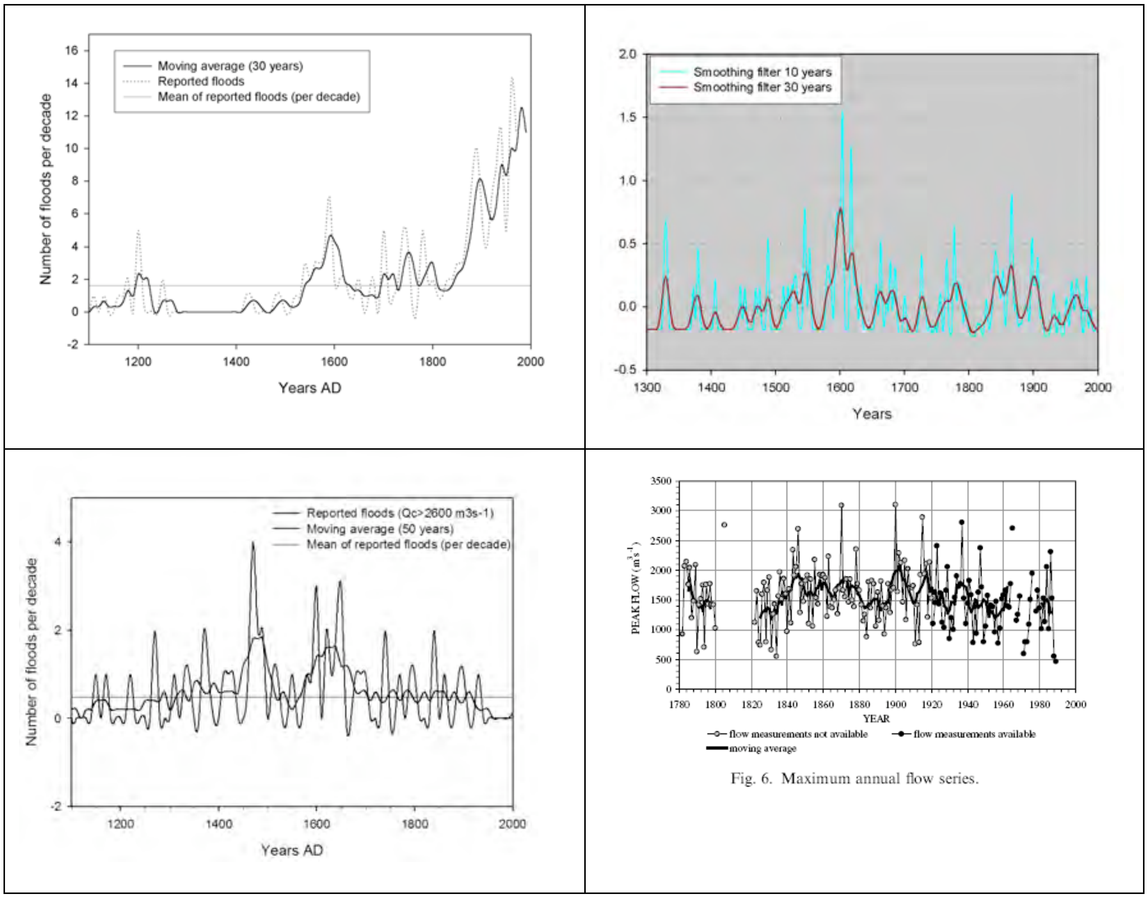


Figure 4-6: Freight handling port facilities at risk from storm surge of 5.5 and 7.0 m in the US Gulf coast (From CCSP, 2008, Fig. 4.20).



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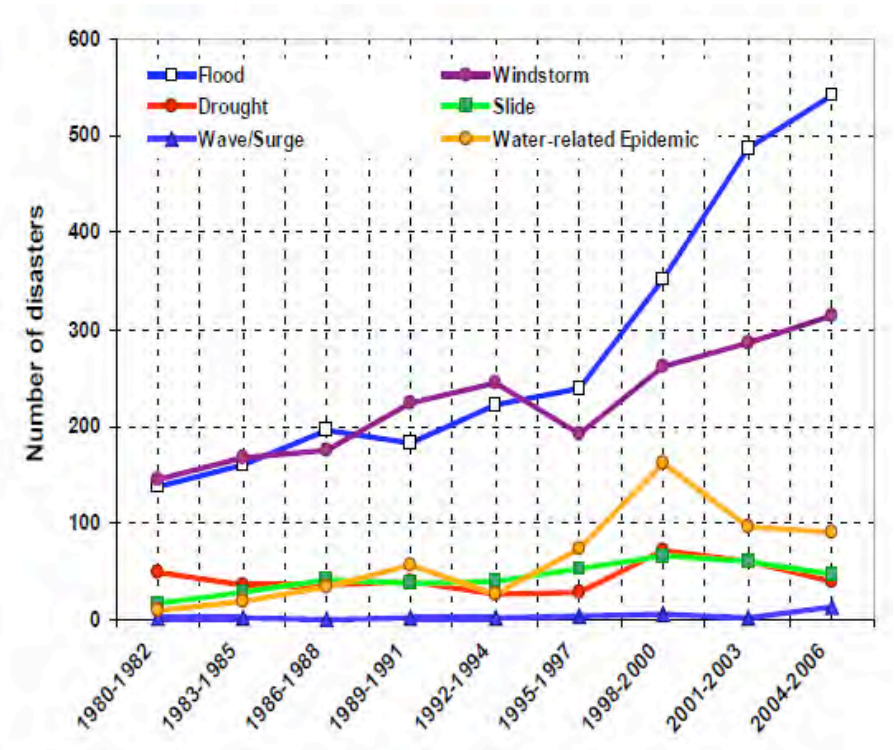

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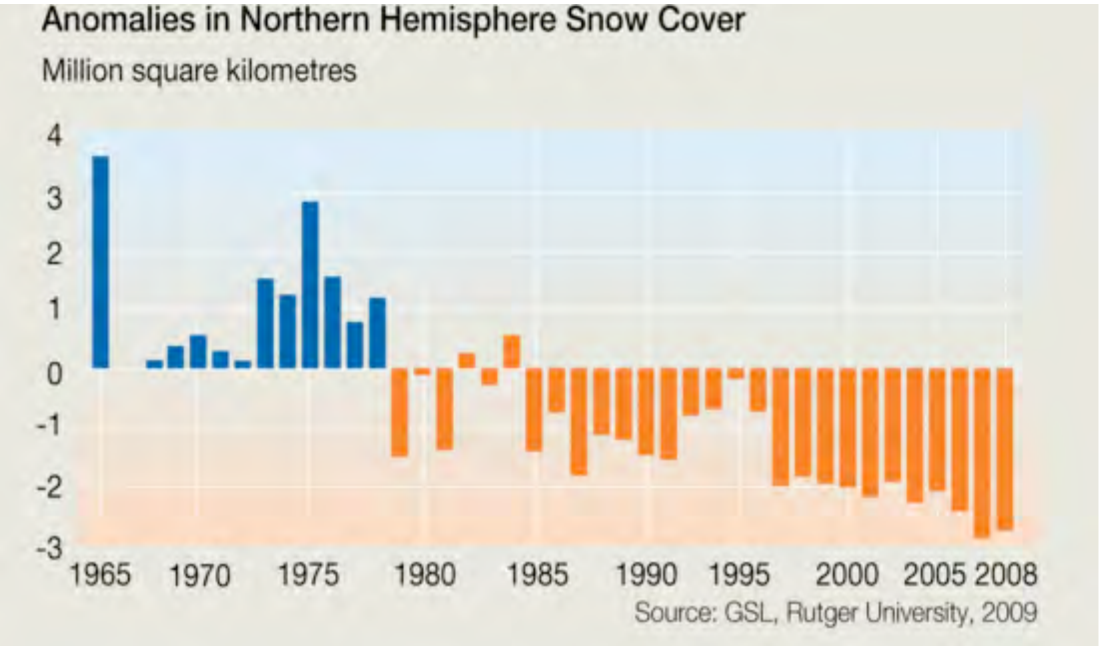

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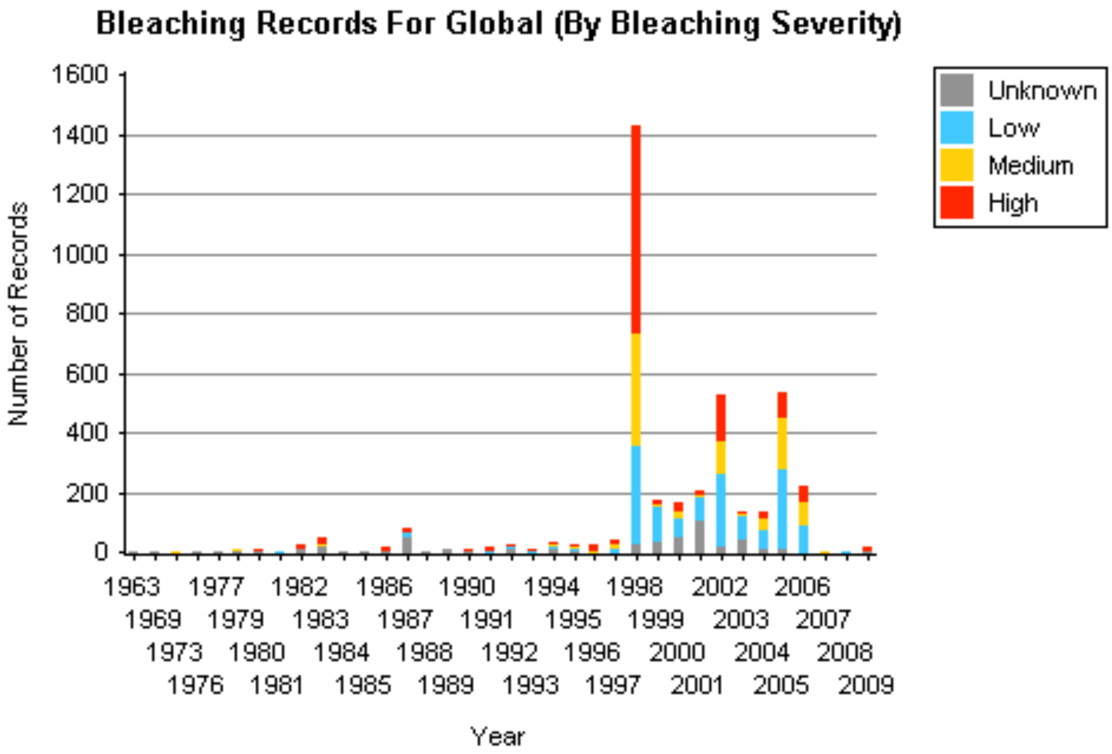

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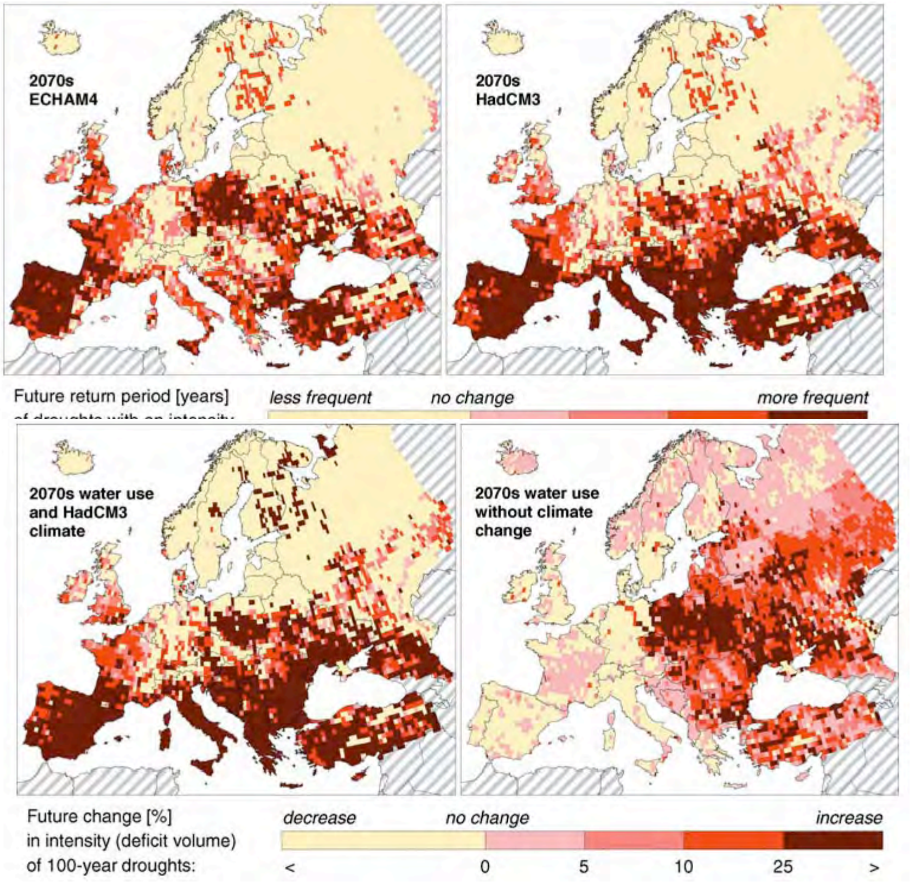

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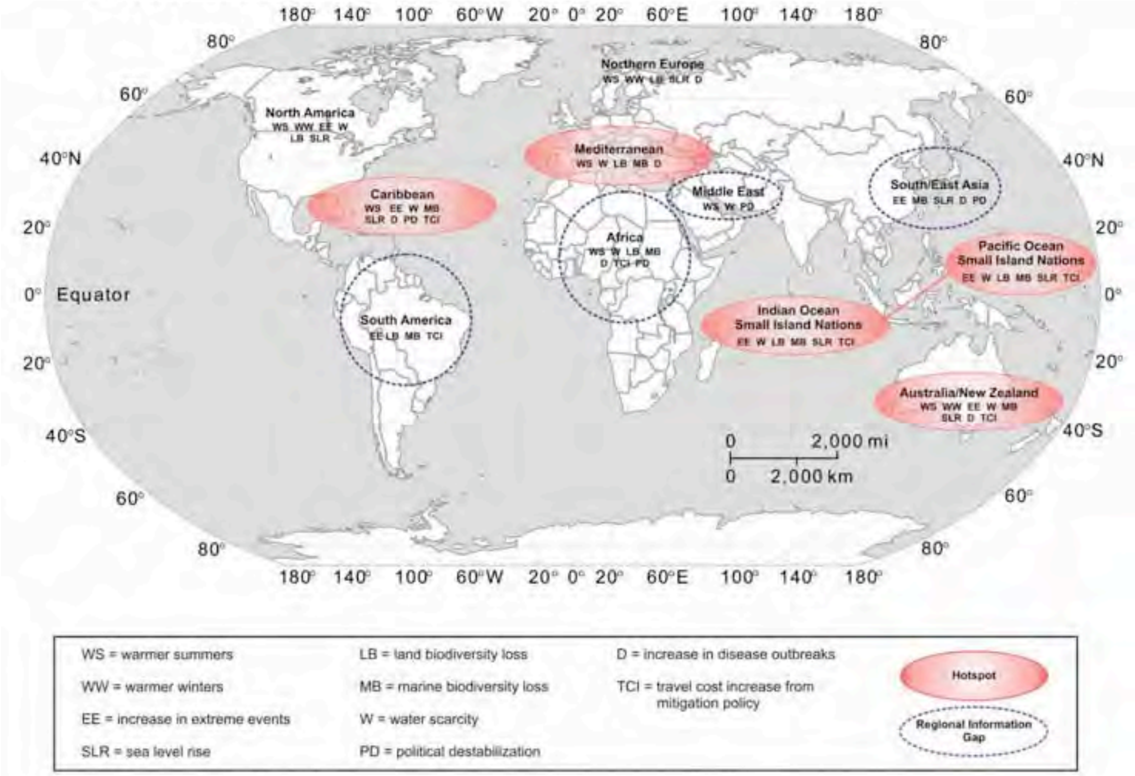

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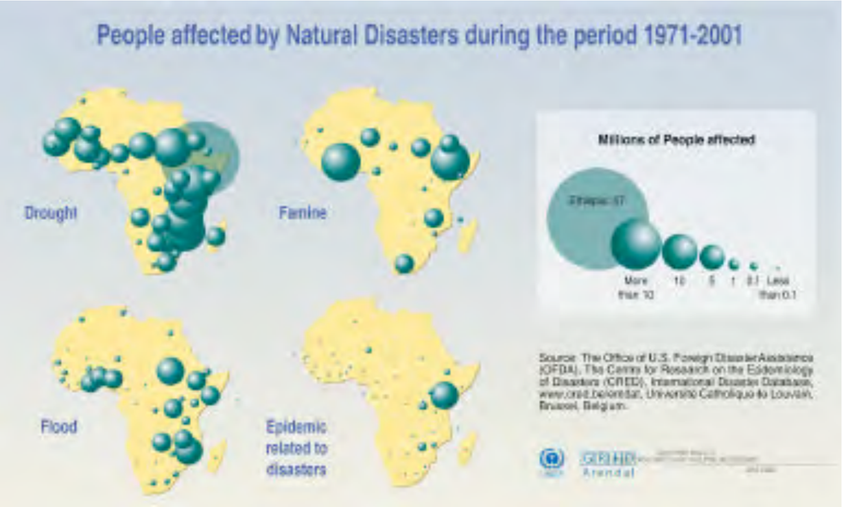

Source: The Office of U.S. Foreign Disaster Assistance (OFDA), The Centre for Research on the Epidemiology of Disasters (CRED), International Disaster Database, www.cred.be/emdat, Université Catholique de Louvain, Brussel, Belgium.

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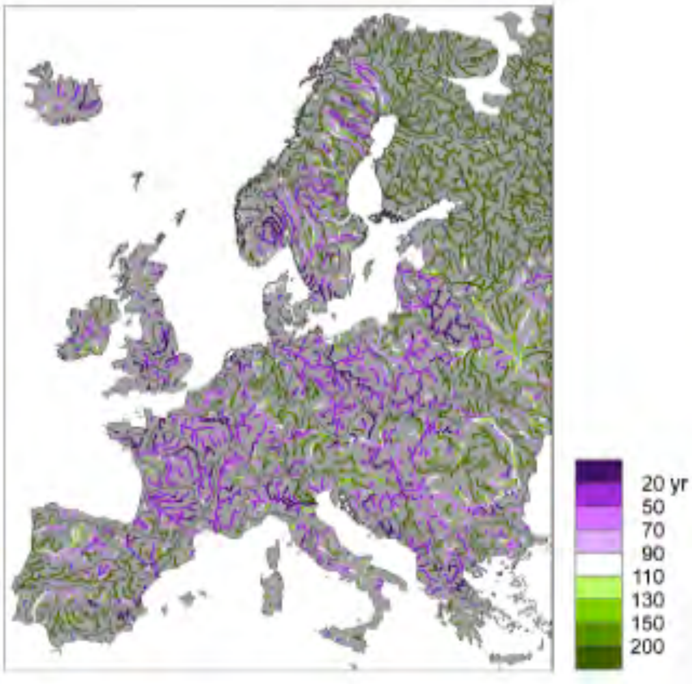

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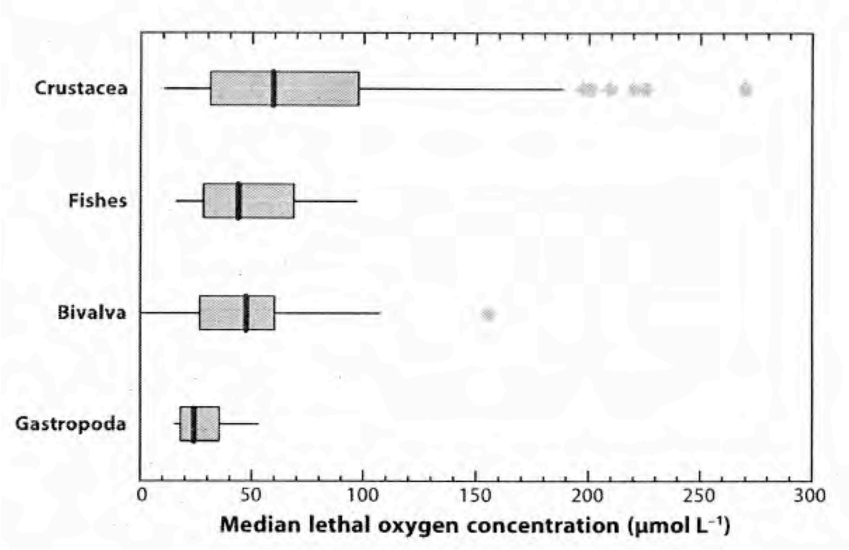

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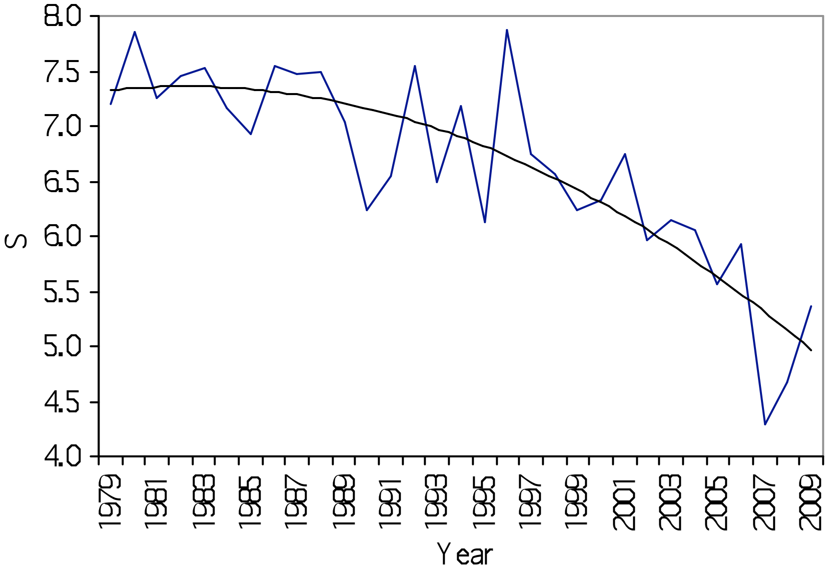

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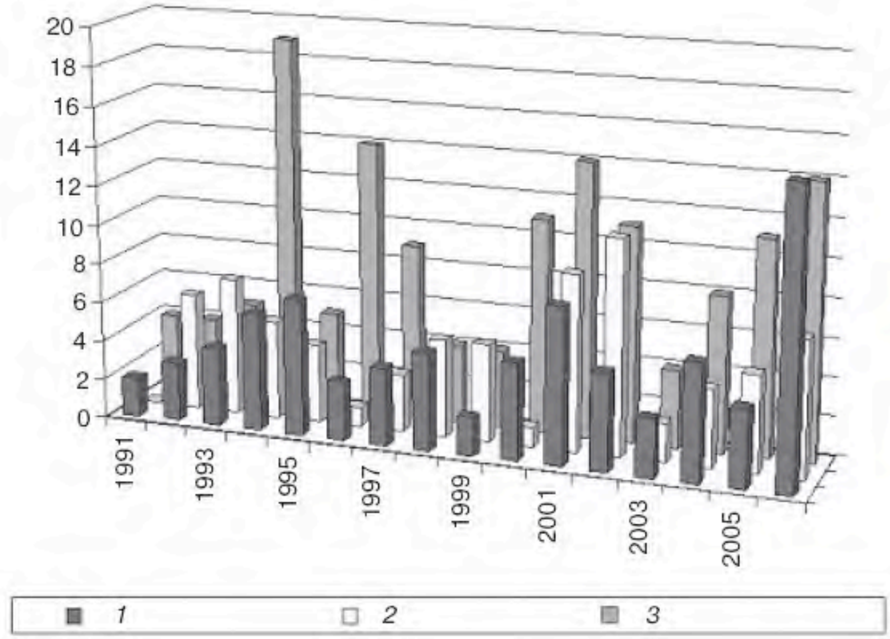

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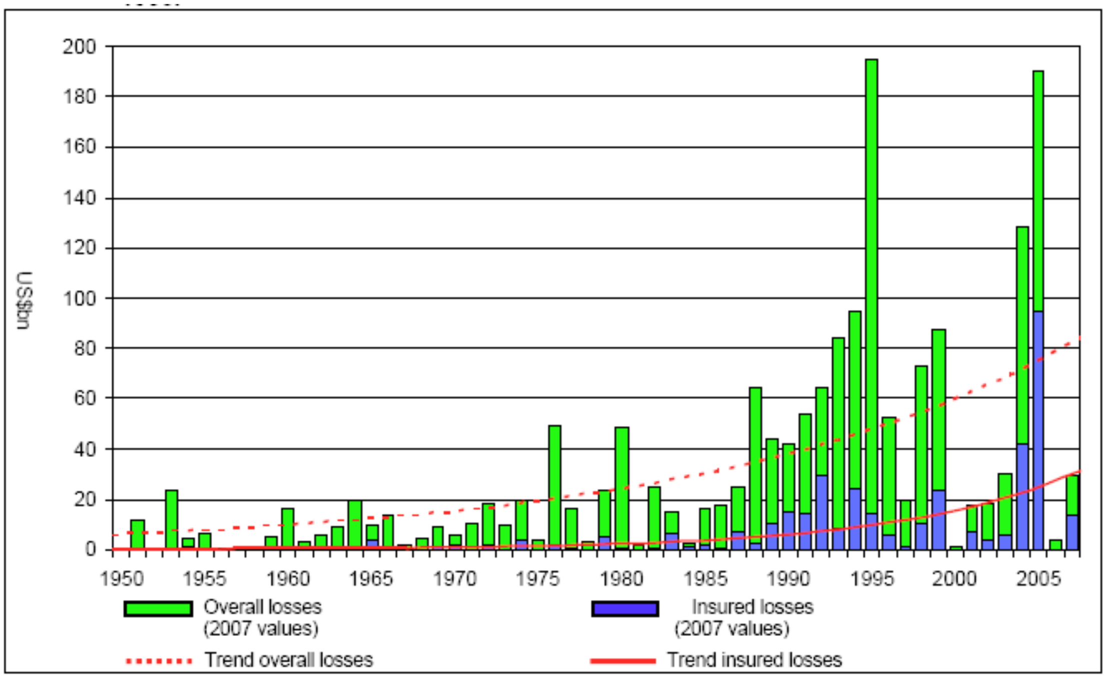

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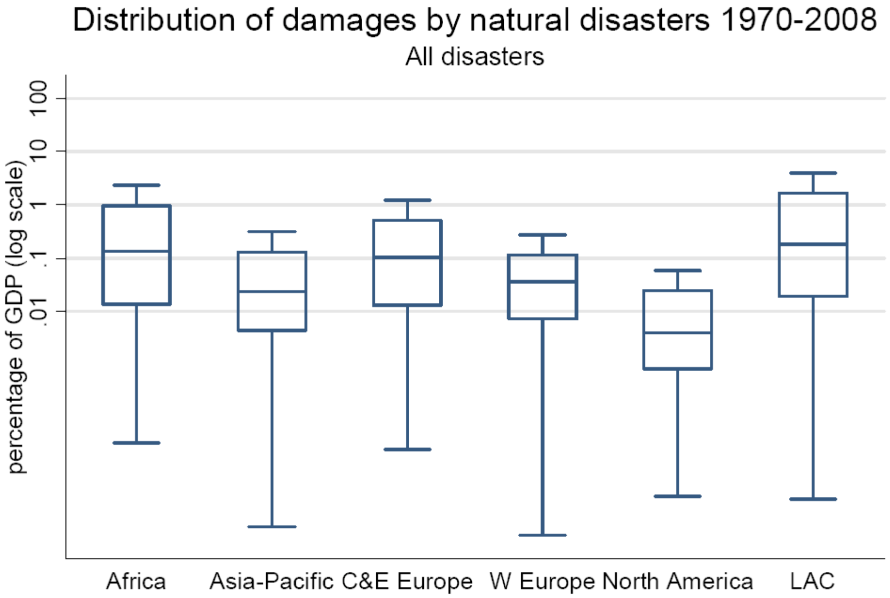

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Source: EM-DAT, WDI database, calculated by Cavallo, Noy (2009).

Chapter 5. Managing the Risks from Climate Extremes at the Local Level

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Executive Summary

Local refers to a range of places, social groupings, experience, management, institutions, conditions and sets of knowledge that exist at a scale below the national level. **Locales range from communities, villages, districts, suburbs, cities, metropolitan areas through to regions. Therefore they vary greatly in terms of disaster experience, nature of impact and responses, and stakeholders and decision-makers. [5.1]**

Disasters triggered by extreme events are most acutely experienced at the local level and numerous strategies to deal with extreme events have been developed at this scale with varying degrees of effectiveness. **Most adaptation to climate change effects on extreme events will take place at the local level. Some places have considerable experience with short-term climatic variability and this may provide the basis for longer-term adaptation to climate extremes. Developing strategies for improving disaster risk reduction in the context of climate change will need to be tailored to local conditions and experiences. [5.1]**

It is important to recognise that there is also great differentiation among locales at the same scale. In particular there are differences between those in developed and developing countries, and between those that are rural and urban. **These differences tend to exist across a continuum rather than being binary. Accordingly, developing strategies for disaster risk management in the context of climate change will require a considerable variety of approaches that reflect the respective local contexts. [5.1]**

There has been an increase in vulnerability at the local level in recent decades. Much of this increase can be attributed to social, political and economic change as well as localised environmental degradation. This trend is particularly evident in developing countries. **This presents a major challenge for adaptation to climate change. Addressing climate change and changing extreme events will require addressing much wider issues relating to sustainable development. [5.1]**

Measures adopted at the local level range from those that help individuals cope during or immediately before extreme events such as evacuation and taking shelter in place (often supported by the provision of early warnings), through structural measures that seek to ‘protect’ people and communities from extremes (e.g. levees, dykes or stop banks, river dredging and straightening, emergency sandbagging and sea walls, measures that seek to counter environmental degradation (such as watershed management) and approaches that seek to avoid (through land use planning and relocation, for example) or offset disaster losses such as surplus food production and its storage. **In many places there is a tendency to rely on structural measures, which encourage settlement and the intensification of livelihoods in places that are believed to be protected. In the event of supra-design events even greater disasters unfold and there is a greater dependence upon relief and reconstruction, and reliance on external sources of assistance [5.2, 5.3].**

Disaster relief and reconstruction may be seen as activities that are required to make up for failures of disaster risk reduction measures to be effective. **Relief plays an important humanitarian role but it does have associated problems including inappropriate forms of assistance, removal of local autonomy in post-disaster decision making and the undermining of local disaster reduction measures. [5.2]**

Following disasters the recovery and reconstruction phases offer opportunities to ‘build back better’. However experience indicates that this is difficult for many localities were there are limited spatial options for relocation or limited financial resources for improving structural and livelihood resilience. **Successful adaptation to climate change will need to address these issues. [5.3]**

There is a strong and complex link between local livelihood security and extreme events. **While communities with secure sustainable livelihoods are likely to be better placed to cope with climate change and changing patterns of climatic variability, extreme events may also undermine local sustainability and increase vulnerability. Building sustainable livelihoods is an important adaptation to climate change. [5.3]**

Managing risk in the context of climate change offers a range of opportunities and challenges at the local level. **The mix of opportunities and challenges is likely to be unique for each locality or community. For this reason generic approaches are likely to be unsuccessful. [5.3]**

Components of localised disaster risk management in the context of climate change include: anticipating risks as affected by climate change; communicating likely changes in disaster risk to enable local action; empowering local communities to enable them to use their local knowledge and information supplied to them to develop locally appropriate strategies; encouraging, strengthening and or building on existing local social networks (and drawing on local socil capital) as a basis for sustainable risk management; integrating and valuing local knowledge which for many localities is much more place specific than other forms of knowledge including that derived from climate models; and facilitating local government and non-government initiatives and practices. **Many of these components of localised disaster risk management in the context of climate change are consistent with the building of local capacities and sustainable livelihoods. [5.3]**

There are significant challenges to disaster risk management with certain groups experiencing greater levels of vulnerability. **These inequalities reflect gender, age, wealth (class), ethnicity, health and disabilities. For many individuals and communities these may coalesce further intensifying vulnerability. They may also be reflected in differences in access to livelihoods and entitlements, or declining access also lead to reductions in vulnerability. [5.4]**

The rapid urbanisation of the global population and the growth of megacities, especially in developing countries, have led to the emergency of highly vulnerable urban communities, especially those in informal settlements. **Addressing these critical vulnerabilities will require addressing their social, political and economic driving forces. These include rural to urban migration, changing livelihoods and wealth inequalities. [5.4]**

The costs of disasters at the local level are difficult to estimate. Similarly, the identification of climate change effects at the local level is complicated. Accordingly, estimating the costs of adapting to changes in climate extremes is also difficult to estimate. **There is a need for further development of tools to enable such costs to be assessed. [5.4]**

Adapting to climate extremes may not be possible in all local settings. **There are many locations that are currently exposed to frequent disruption from extremes and from which displaced people temporarily or permanently migrate. If climate extremes occur more frequently or with greater magnitude (or duration in the case of droughts) in situ adaptation may become ineffective or impossible without severe hardship and suffering. In such cases local places may be rendered uninhabitable with the resulting migration of individuals or relocation of whole communities. For at least some of these migrants there will be serious dislocation and disadvantage as a result of their forced migration. [5.2, 5.4]**

Managing disaster risk at the local level can be achieved using a variety of approaches. There are three key elements including: assessment of local exposure taking into account community location and the suite of likely extreme events and their characteristics such as frequency and magnitude; vulnerability analyses which identify community sensitivities; and post disaster assessment. **Many of these activities can be conducted at the community level, using community resources and local knowledge. It may also be beneficial for local knowledge to be combined (though not subsumed by) with other information such as may be generated by climate researchers, disaster reduction agencies and development practitioners (including both governmental and non-governmental organisations). [5.5]**

There is also considerable potential for transfers within communities, among communities and between communities and other levels (national and international). **These include social transfers such as through kinship networks, social protection programmes that seek to assist poorer community members and reduce vulnerability, insurance and micro insurance which spreads losses from extreme events both temporarily and spatially. [5.2, 5.5]**

Disaster risk management in the context of climate change is a process. **Adaptation to changing climate extremes, together with changing mean conditions, is not a set of finite actions but an ongoing process incorporating long-term learning, changing scenarios, and incorporating changes that are not climate related. There is a need for institutional change from top-down approaches to ones that increase local capacities and build resilience. Accordingly adaptation strategies need to be comprehensive, set in the context of sustainable development and flexible. Financial support for adaptation may be required for long periods of time. [5.5]**

There remains a need for a comprehensive database or inventory of disaster occurrence, disaster effects and disaster response. **While there is a vast amount of information about specific events at different scales very little is coordinated at levels below the national.** Geospatial and other technologies exist for the management of sub-national disaster data and these should be carefully utilised. **[5.6]**

5.1. Introduction

As we enter into the second decade of the 21st Century, human and economic losses from weather-related catastrophes continues to increase. In terms of overall losses, 2005, 1995, and 2008 rank among the most expensive years for natural hazard monetary losses worldwide (Geo Risks Research, 2009). Climate variability and change is probably contributing to these weather-related extremes (see Chapter 3) and in combination with human settlement patterns, increasing the exposure to loss throughout the world. However, such losses will not be uniformly distributed across the globe, nor will their impacts. Some communities will be able to cope with disaster risks, while others have limited disaster resilience and capacity to cope with and adapt to climate variability and extremes. This is the topic of this chapter: to present evidence on where disasters are experienced, how disaster risks are managed at present, and the variability in coping mechanisms and capacity in the face of climate variability and change, all from the perspective of local places and local actors.

The impacts of disasters are most acutely felt at the local level. However, the word local has many connotations, and the definition of local influences the context for disaster risk management, the experience of disasters, and conditions, actions and adaptation to climate changes. For the purposes of this report, we define local as the set of experiences and management that arise from grass roots actions; indigenous knowledge, skills, and resources about the place; and formal and informal governance structures. Local includes the set of institutions that maintain and protect social relations that are below state and province levels such as local government, local judiciary, or local licensing authorities which normally have some administrative control over space or resources. Local includes the set of conditions and knowledge that are geographically and historically bounded and where choices and actions for disaster risk management and adaptation to climate extremes are initially independent of national interventions. Local includes functional or physical units such as watersheds, ecological zones, or economic regions, and the institutions that govern their use and management. Within the local level, there are many different locales (the explicit spatial boundaries of different settings or collectives where social interactions occur). These locales can range from a community, village, district, suburb, city, metropolitan area, region—all with distinct spatial and jurisdictional boundaries, and different needs, identities, and voices. The differences in scale not only influence who and what is at risk, but more importantly the potential geographical extent of the likely impact, and the likely stakeholders and decision-makers.

One particular type of locale of interest to this chapter is community. A community is a group of people (larger than households) who interact with one another and who live in a common location (community of location) (Johnston, 2000). But a community is also defined as a group of people organized around a set of common values or ideals such as religious values, ethnic identities, professional practice, etc. We use the term community to refer to both: a spatially-defined entity with social interaction among residents; and the collection of relationships or social bonds that are a-spatial (communities of propinquity or communities of culture), but which influence opportunities and actions at the local level. Community-based management includes both the community of location and the communities of culture.

Local places have considerable experience with short-term coping responses and adjustments to disaster risk (UNISDR, 2004). Climate sensitive hazards such as flooding, tropical cyclones, drought, heat, and wildfires regularly affect many localities with frequent, yet low level losses (UNISDR, 2009). Because of their frequent occurrence, many localities have developed extensive disaster risk management practices, suggesting a form of climate-sensitive coping that is already in place. On the other hand, response and long term adaptation to climate extremes will require disaster risk management that acknowledges the role of climate variability in fostering sustainable and disaster resilient places in the face of climate change and uncertainties. This can mean a modification and expansion of local disaster risk management principles and experience through innovative organizational, institutional, and governmental measures at all jurisdictional levels (local, national, international). However, such arrangements may constrain or impede local actions and ultimately limit the coping capacity and adaptation of local places.

In preparing this chapter we have been struck by the considerable range of climate-sensitive risk experience at the local level and the great variety of strategies that have been developed to reduce risk. Climate risks are mediated by culture, class, society, economy, politics and local environmental conditions. The structure of this chapter is thematic rather than regional or based on development status. However, it is important to keep these factors in mind.

While the differences in the effects of natural disasters among countries is usually demonstrated using data at the national level (e.g, EM-Dat; IFRC), the differential effects are experienced at the local level and many measures to reduce disaster risk will also be applied at this scale. One of the most striking differences in vulnerability is that which distinguishes communities in developing countries from those in the industrialized nations. In this chapter we have addressed the issue of local disaster risk and disaster risk reduction using a variety of sources of information (see Box 5-1). However, given the wide differences between developing and developing countries it is clear that single solutions for risk reduction are unlikely to be possible. Moreover, it is possible that the processes of development as currently practiced, in addition to a history of colonial exploitation, may be increasing, rather than reducing disaster vulnerability at the local level. Those choosing strategies for reducing disaster risk and adapting to climate change in developing countries need to take these processes into account. Similarly, there are differences between urban and rural communities in terms of disaster and climate change vulnerability and disaster risk and adaptation options. For example, in many rural areas livelihoods have a strong subsistence component (i.e. the producer is the consumer) and climate impacts may have considerably more direct effects than upon some urban dwellers whose livelihoods may be less dependent upon climatic conditions. Conversely, the effects of heat waves are often more severe in urban than rural areas.

_____ START BOX 5-1 HERE _____

Box 5-1. Capturing Local Knowledge: The Use of Grey Literature

What is grey literature? Grey literature non-journal based sources of information, data, and analyses that have not gone through the traditional scientific peer review process that is the norm for refereed journal publications. According to the Sixth International Conferences on Grey Literature, it is “information produced on all levels of government, academics, business and industry in electronic or print formats not controlled by commercial publishing, i.e. where publishing is not the primary activity of the producing body” (www.greynet.org, accessed

May 18 2010). Grey literature is formal, unpublished scientific and technical communication ((Sondergaard *et al.*, 2003)) and includes reports (policy statements, technical reports, government documents, project reports, annual reports), working papers, conference proceedings and papers, theses and dissertations, brochures and pamphlets, audiovisual materials, and internet-based materials. The use of grey literature varies widely by scientific field. In economics, for example working paper series are quite common, but their impact (based on citations) is similar to low impact journals ((Frandsen, 2009)). Much disaster risk management literature, especially in, or relating to developing countries falls into this categories. Such literature includes key themes in disaster risk management such as those produced by the International Strategy for Disaster Reduction (ISDR), national level reports by governmental agencies, country reports, and project reports at various local levels. While the grey literature is not always peer reviewed in an academic sense, much of it is subjected to some form of review ranging from widespread consultation with peers outside the agency or entity to in house checking. In some instances, such as with IPCC reports and World Bank reports, it is often more rigorously peer reviewed than some journals.

In recent years grey literature has made critical contributions to a number of projects on environmental change ((Chavez *et al.*, 2007; Costello, 2007)(Thatje *et al.*, 2007);) including intergovernmental scientific research ((MacDonald *et al.*, 2007)) This includes the IPCC, where the Fourth Assessment clearly states, “Its emphasis is on new knowledge acquired since the IPCC Third Assessment (2001). This requires a survey of all published literature, including non-English language and ‘grey’ literature such as government and NGO reports ((Parry *et al.*, 2007)).” However, use of grey literature is challenged by some scientists and other observers who are concerned by its lack of rigor. The advent of the internet has changed the accessibility and availability of grey literature, giving it much wider circulation and in many cases increased status.

Why Use Grey Literature? There are a number of reasons why grey literature is used. First, there is a dearth of peer-reviewed research covering community/local level disaster risk management and climate change adaptation. This is especially true for developing countries. While a small amount of refereed literature is emerging, it may not be published in sufficient quantity or in a timely fashion to be included in this report. Second, much of the community based work is not conducted by researchers motivated to publish in peer-reviewed journals. Instead, the motivation for the research is action-oriented (focus on doing, not observing). In many instances the career paths of the researchers are not dependent on peer-reviewed research, but rather actionable results. Third, in many developing countries there is less of a tradition of publishing in scientific journals, oftentimes due to the qualitative nature of the work. Instead, most of the literature on disaster risk appears in reports from governments and organizations. Finally, there is a concern on the part of many field investigators that research interferes with the ethos of participatory and action research approaches. Failure to include the grey literature will bias our findings toward developed country disaster risk management and adaptation.

Who Writes Grey Literature? Grey literature is created by a very wide range of actors including research scientists, especially but not exclusively those working in non-academic institutions, and researchers working as private consultants. A great deal of grey literature is generated by governments including international (e.g. ISDR, UNDP, World Bank) and regional (Secretariat of the Pacific Regional Environment Program) intergovernmental organizations and national and local government agencies. In addition to these sources grey literature may also be prepared by non-governmental organizations and civil society (at the international, regional, national and local levels). The authors of GL also range is qualification from those with PhDs and/or those with considerable practical or policy experience through to some with little or no tertiary education at all. A significant proportion of the grey literature accessed for this chapter has been written by individuals with PhDs and strong (refereed) publication records and there is a steady contribution from researchers retired from their institutional bases that work on contract.

How Do We Assess Quality? A major concern with grey literature is the assessment of quality given that it often has not been subject to an academic process of peer review as is the case with journal articles. How can we assess the quality as good?

The following are a set of approaches that were utilized in this report. First, we can apply our own internal peer review. Most of the working group members have experience at peer review and have been involved in assessment of journal articles and other research products and can apply the same standards. This could be assisted by the provision of guidelines (see Table 5-1). Second, we could send reports to other members of report team who have relevant expertise for a secondary evaluation. For example, the requesting chapter team would need to be explicit about the qualities of the report and why it has been included to the secondary reviewer, who would then conduct an independent evaluation of that section of the document to be used. In order to ensure transparency of the process, the secondary review would ideally be conducted by someone outside the immediate chapter writing team such as the review editor. Third, a process of triangulation could be employed using separate reports that reinforce the same issue although it is important to ensure that they are not related (emanating from the same organisation or author). Fourth, grey literature should only be used where peer reviewed material is not available. Figure 5-1 indicates a possible flow path for accepting grey literature for this chapter and the special report.

[INSERT TABLE 5-1 HERE:
Table 5-1: Guidelines for grey literature inclusion.]

[INSERT FIGURE 5-1 HERE:
Figure 5-1: Procedure for assessing grey literature.]

Practitioner experience and local knowledge are key components in understanding disaster risk management and climate change adaptation at the local level. Failure to include the grey literature in this assessment will result in a great majority of vulnerable communities being excluded from the IPCC process as their voices and experiences will not be heard, nor represented in the assessment.

_____ END BOX 5-1 HERE _____

Finally, it is also very important not to treat these considerations in a binary manner (see Figure 5-2). The wealth, level of industrialization or development status of communities ranges in a continua from those in least countries to those in the wealthiest of nations. Similarly, the rural-urban divide is blurred, and the size of urban areas ranges from mega cities to small towns. Along these continua lie a great variety of vulnerabilities, experiences and possibilities for adaptation (represented by the grey area).

[INSERT FIGURE 5-2 HERE:
Figure 5-2: The continuum of development and urbanization.]

There are a number of key themes and messages in the chapter. First, some local places have considerable experience with short-term climate-sensitive hazards on a fairly routine basis. This knowledge can provide the basis for longer-term adaptation to climate variability and extremes. Second, improvements in any type of disaster risk management may have local benefits independent of climate change and such improvements will help foster disaster resilience in the short- and long-term. Finally, long-term adaptation to climate will require that disaster risk management explicitly consider climate variability and change. Strong and flexible climate and disaster risk management agencies may not require new institutional structures, although there will be exceptions. Shared responsibilities for coping and adaptation are needed to harness local knowledge, experience, and action and integrate this into the more top-down strategies emanating from national and international disaster risk management and adaptation to climate change strategies. A one-size strategy will certainly not fit all at the local level.

5.2. Community Coping

Communities everywhere have developed ways of interacting with their environment. Often these interactions are beneficial and provide the livelihoods that community members depend on. At the same time communities have developed ways of responding to disruptive environmental events. These coping mechanisms include measures which seek to modify the impacts of disruptive events, modify some of the attributes or environmental aspects of the events themselves, and/or actions to share or reduce the disaster risk burdens (Burton *et al.*, 1993). It is important to acknowledge that while climate change may alter the magnitude and/or frequency of some climatic extremes, other social, political, or economic processes (many of them also global in scale) are reducing the abilities of communities to cope with disaster risks and climate-sensitive hazards. Accordingly, disaster losses have increased significantly in recent decades ((UNDP, 2004; UNISDR, 2004)). These social, economic, and political processes are complex and deep seated and present major obstacles to reducing disaster risk, and are likely to constrain efforts to reduce community vulnerabilities to extreme events under conditions of climate change.

There are a variety of existing measures that local communities utilize in coping with disaster risk. These include pre-event activities such as disaster risk education and early warning systems; individual and collective protective actions such as evacuation; prevention strategies such as structural measures (seawalls and levees); non-structural measures such as land use and ecosystem protection; population displacements (both temporary and permanent), and disaster relief.

5.2.1. Generation, Receipt, and Response to Risk Information

The disaster research and emergency management communities have shown that warnings of impending hazards need to be complemented by information on the risks actually posed by the hazards and likely strategies and pathways to mitigate the damage in the particular context in which they arise. Effective "early warning" implies information interventions into an environment in which much about vulnerability is assumed ((Olson, 2000)(Olson, 2000)). This backdrop is reinforced through significant lessons that have been identified from the use of seasonal climate forecasts over the past 15 years ((Podestá *et al.*, 2002; Pulwarty, 2007)) It is now widely accepted that the existence of predictable climate variability and impacts are necessary but not sufficient to achieve effective use of climate information, including seasonal forecasts. The practical obstacles to using information about future conditions are diverse, ranging from limitations in modeling the climate system's complexities (e.g. projections having coarse spatial and temporal resolution, limited predictability of some relevant variables, and forecast skill characterization), to procedural, institutional, and cognitive barriers in receiving or understanding climatic information, and the capacity and willingness of decision-makers to modify actions ((Kasperson *et al.*, 1988; Marx *et al.*, 2007; Patt and Gawa, 2002; Roncoli *et al.*, 2001; Stern and Easterling, 1999)). In addition functional, structural, and social factors inhibit joint problem identification and collaborative knowledge production between providers and users. These include divergent objectives, needs, scope, and priorities; different institutional settings and standards, as well as differing cultural values, understanding, and mistrust ((Pulwarty *et al.*, 2004; Rayner *et al.*, 2005; Weichselgartner and Kasperson, 2010)).

The generation and receipt of risk information occurs through a diverse array of channels. Policies and actions affecting communications and advanced warning have a major impact on the adaptive capacity and resilience of livelihoods with for example, access to reliable and low cost telecommunications services are central factors influencing the ability of local populations to diversify their income strategies. The collection and transmittal of weather (and climate)-related information is, often a governmental function while communications systems such as cell phone networks tend to be private.

Examples of risk information generation and diffusion efforts within disasters research and response communities including- interpersonal contact with particular researchers, planning and conceptual foresight (Red Cross/Red Crescent brochures), outside consultation on the planning process (FEMA), user-oriented transformation of information and individual and organizational leadership ((NRC (National Research Council), 2006)) (see Box 5-2 for additional sources of risk information).

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Box 5-2. Selected Sources of Risk Information

There are many sources of risk, vulnerability, and warning information. Among them are the Asia Disaster Preparedness Centre, Natural Hazards Research and Applications Information Center, at the University of Colorado, South Carolina Hazards and Vulnerability Research Institute, Caribbean Disaster Emergency Management Agency, Latin America Vulnerability Project, National Early Warning Units, in Southern Africa, National Weather Service (NWS) Warning Program and the NOAA/Columbia University International Research Institute for Climate and Society. More generally the space in which problem definition, information needs assessments, and knowledge co-production is usually takes the form of:

- Workshops and meetings (shared scenario construction including agro-climatic decision calendars
- Presentations and briefings (incl. locally organized events, e.g. hearings)
- One-on-one technical assistance and training
- Coordination with other ongoing projects
- Web site development and maintenance
- Courses on climate impacts and adaptation (see below)
- Media (local and mass media and information telenovelas etc.)

((Perarnaud *et al.*, 2004; Pulwarty, 2007; Van Aalst *et al.*, 2008))

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Significant advancements in warning systems in terms of improved monitoring, instrumentation, and data collection have occurred, but the management of the information and its dissemination to at risk populations is still problematic ((Sorensen, 2000)). Researchers have identified several aspects of information communication, such as, communication channels, stakeholder awareness, key relationships, and language and terminology, which are socially contingent in addition to the nature of the predictions themselves. More is known about the effects of these message characteristics on warning recipients, than is known about the degree to which generators and providers of information including hazards researchers address them in their risk communication messages. For example, warnings may be activated (such as the tsunami early warning system), yet fail to reach potentially affected communities ((Oloruntoba, 2005)). Similarly, many communities do not have access to climate-sensitive hazard warning systems such as tone alert radio, emergency alert system, reverse 911, and thus never hear the warning message, let alone act upon the information ((Sorensen, 2000)). On the other hand, Valdes ((Valdes, 1997)) demonstrated that flood warning systems based on community operation and participation in Costa Rica make a difference as to whether early warnings are acted upon to save lives and property.

5.2.2. Individual/Collective Action

At the individual and household level, individuals engage in protective actions to minimize the impact of extreme events on themselves and their families. The range and choice of actions are often event specific and time dependent, but they are also constrained by location, adequate infrastructure, socioeconomic characteristics, and access to disaster risk information (Tierney *et al.*, 2001). For example, evacuation is used when there is sufficient warning to temporarily relocate out of harm's way such as for tropical storms, flooding, and wildfires. Collective evacuations are not always possible given the location, population size, transportation networks, and the rapid onset of the event. At the same time, individual evacuation may be constrained by a host of factors ranging from access to transportation, monetary resources, health impairment, job responsibilities, and the reluctance to leave home. There is a consistent body of literature on hurricane evacuations in the U.S., for example which finds that 1) individuals tend to evacuate as family units, but they often use more than one private vehicle to do so; 2) social influences (neighbors, family, friends) are key to individual and households evacuation decision-making; if neighbors are leaving then the individual is more likely to evacuate and vice versa; 3) risk perception, especially the personalization of risk by individuals is a more significant factor in prompting evacuation than prior adverse experience with hurricanes; and 4) social and demographic factors (age, presence of children, elderly, or pets in households, gender, income, disability, and race or ethnicity) either constrain or motivate evacuation depending on the particular context ((Adeloa, 2009; Bateman and Edwards, 2002; Dash and Gladwin, 2007; Dow, K. and Cutter, S. L., 2002; Dow and Cutter, 1998; Dow and Cutter, 2000; Edmonds and Cutter, 2008; Lindell *et al.*, 2005; McGuire *et al.*, 2007; Perry and Lindell, 1991; Sorensen *et al.*, 2004; Sorensen and Sorensen, 2007; Van Willigen *et al.*, 2002; Whitehead *et al.*, 2000)).

A different protective action, shelter-in-place occurs when there is little time to act in response to an extreme event or when leaving the community would place individuals more at risk (Sorensen *et al.*, 2004). Seeking higher ground or moving to higher floors in residential structures to get out of rising waters is one example. Another is the movement into interior spaces within buildings to seek refuge from strong winds. In the case of wildfires, shelter in place becomes a back-up strategy when evacuation routes are restricted because of the fire and then include protecting the structure or finding a safe area such as a water body (lake or backyard swimming pool) as temporary shelter ((Cova *et al.*, 2009)). In Australia, the shelter in place action is slightly different. Here there is local community engagement with wildfire risks with stay and defend or leave early (SDLE) policy. In this context, the decisions to remain are based on social networks, prior experience with wildfires, and involvement with the local fire brigade ((McGee and Russell, 2003)). The study also found that rural residents were more self-reliant and prepared than suburban residents ((McGee and Russell, 2003)).

The social organization of societies dictates the flexibility in the choice of protective actions—some are engaged in voluntarily (such as in the U.S., Australia, and Europe), while other protective actions for individuals or households are imposed by state authorities such as Cuba and China. Planning for natural disasters is a way of life for Cuba, where everyone is taught at an early age to mobilize quickly in the case of a natural disaster ((Bermejo, 2006; Sims and Vogelmann, 2002). The organization of civil defense committees at block, neighborhood, and community levels working in conjunction with centralized governmental authority makes the Cuban experience unique ((Bermejo, 2006)(Sims and Vogelmann, 2002)).

In many traditional or pre-capitalist societies it appears that mechanisms existed, which protected community members from periodic shocks such as natural hazards. These mechanisms which are sometimes referred to as the *moral economy*, were underpinned by reciprocity, often linked to kinship networks, and served to redistribute resources to reduce the impacts on those who had sustained severe losses and were identified by Scott ((Scott, 1976)) in Southeast Asia, Watts ((Watts, 1983)) in Western Africa and Paulson ((Paulson, 1993)) in the Pacific Islands. The moral economy incorporated social, cultural, political and religious arrangements which ensured that all community members had a minimal level of subsistence (see Box 5-3).

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Box 5-3. Collective Behavior and the Moral Economy at Work

One example of such a system is the *Suqe*, or graded society, which existed in northern Vanuatu. In the *Suqe* 'big men' achieved the highest status by accumulating surpluses of valued goods such as shell money, specially woven mats and pigs. Men increased their grade within the system by making payments of these goods to men of higher rank. In accumulating the items men would also accumulate obligations to those they had borrowed from. Accordingly networks and alliances emerged among the islands of northern Vanuatu. When tropical cyclones destroyed crops, the obligations could be called in and assistance given from members of the networks who lived in islands that escaped damage ((Campbell, 1990)). A variety of socio-political networks, that were used to offset disaster losses, existed throughout the Pacific region prior to colonization ((Campbell, 2006) (Paulson, 1993; Paulson, 1993; Sahlins, 1962)). A number of processes associated with colonialism, the introduction of the cash economy and conversion to Christianity, as well as the provision of post-disaster relief has caused a number of elements of the moral economy to fall into disuse ((Campbell, 2006)).

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There is some controversy over the significance of the notion of moral economy with some writers claiming that it oversimplified intra- and inter-community linkages in pre-capitalist settings. In doing so it does not recognize the inequalities in some of the social systems that enabled such practices to be sustained and tended to perhaps provide an unrealistic notion of a less risky past. In addition kinship based sharing networks may foster freeloading among some members ((diFalco and Bulte, 2009)). Nevertheless, a reduction in traditional coping mechanisms including the moral economy is reflected in growing disaster losses and increasing dependency on relief ((Campbell, 2006)).

Collective action to prepare for or respond to disaster risk and extreme climate impacts can also be driven by localized organizations and social movements. Many such groups represent networks or first-responders for climate-sensitive disasters. However, there are many constraints that these movements face in building effective coalitions including the need to connect with other movement organizations and frame the problem in an accessible way ((McCormick, 2010)).

5.2.3. Structures and Structural Mitigation

Structural interventions to reduce the effects of extreme events generally refer to engineering work like dykes, embankments, seawalls, river channel modification, flood gates, and reservoirs, etc. Although these structural interventions can achieve success in reducing disaster impacts, they can also fail due to lack of maintenance or due to extreme events. Most structural measures are short-term solutions. Furthermore, technical considerations should not preclude socio-economic considerations ((WMO, 2003)). Implementing structural measures that involve participatory approaches from communities who are proactively involved often leads to more sustainable outcomes. One of the key reasons why local projects are often ineffective is that they are approved on the basis of technical information alone, rather than based on both technical information and local wisdom ((ActionAid, 2005)). In addition, national legislation can have important influences on the choice of disaster risk reduction strategies at the local level as can local and national institutional arrangements that often favor technocratic responses over other non-structural approaches ((Burby, 2006)).

The method of protecting an entire area by building a dyke has been in use for thousands of years and is still being applied by communities in flood-prone countries. Embankments, dykes, levees and floodwalls are all designed to protect areas from flooding by confining the water to a river channel, thus protecting the areas immediately behind them. Building dykes is one of the most economical means of flood control ((Asian Disaster Preparedness Centre, 2005)). Dykes built by communities normally involve low technology and traditional knowledge (such as earth embankments as shown in Figure 5-3). Sand bagging is also very popular for flood-proofing in Asia. Generally, structures that are built of earth are highly susceptible to erosion leading to channel siltation and reduced water conveyance on the wet side and slope instability and failure on the dry side. It can also reduce the height of the structure making it less effective. Slopes can be stabilized by various methods, including turfing by planting vegetation such as Catkin grass and Vetiver grass in Bangladesh and Thailand, respectively.

[INSERT FIGURE 5-3 HERE:
Figure 5-3: Earth embankment along the river (left) with stabilization (right) (ADPC, 2005).]

Large scale structural measures are often implemented using cost-benefit analyses and technical approaches. In many cases, particularly in developed countries, structural measures are subsidized by national governments and local governments and communities are required to cover only partial costs. In New Zealand this led to a preponderance of structural measures despite planning legislation that enabled non-structural measures. As a result the catastrophic potential was increased and development intensified in ‘protected’ areas only to be seriously devastated by supra-design events ((Ericksen, 1986)). This so-called “levee effect”, actually increases disaster risk rather than decreasing it ((Montz and Tobin, 2008; Tobin, 1995)). Reduction of centralized subsidies in the mid-1980s and changes in legislation saw greater responsibility for the costs of disaster risk management falling on the communities affected and a move towards more integrated disaster risk reduction processes within New Zealand ((Ericksen *et al*., 2000)).

Building codes closely align with engineering and architectural structural approaches to disaster risk reduction ((Kang *et al*., 2009)(Petal *et al*., 2008)). This is accompanied by the elevation of buildings and ground floor standards in the case of flooding ((Kang *et al*., 2009)). One dilemma with building codes is their implementation at the local level. Instances of earthquake and inundation-generated building damages occur because of noncompliance ((Burby *et al*., 1998)).

5.2.4. Land Use and Ecosystem Protection

Changes in land use not only contribute to global climate change but they are equally reflective of adaptation to the varying signals of economic, policy, and environmental change ((Brown, D., A. Agrawal , S. Cheong , R. Chowdhury, C.Polsky, ; Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer, C. Folke, P. S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E. F. Moran, M. Mortimore, P. S. Ramakrishnan, J. F. Richards, H. Skånes, W. Steffen, G. D. Stone, U. Svedin, T. A. Veldkamp,

C. Vogel,J.Xu, 2001)). Disaster management through local land use planning embedded in zoning, local comprehensive plans, and retreat and relocation policies is a popular approach to disaster risk management, although some countries and rural areas may not have formal land use regulations that restrict development or settlement. As land use management regulates the movement of people and industries in hazard-prone zones, it faces development pressures and real estate interests accompanied by property rights and the takings issue ((Burby, 2000; Thomson, 2007; Titus, J., D. Hudgens, D. Trescott, M. Craghan, W. Nuckols, C. Hershner, J. Kassakian, C. Linn, P. Merritt, T. McCue, J. O'Connell, J. Tanski,J.Wang, 2009)). Buffer zones, setback lines in coastal zones, and inundation zones based on flood and sea-level rise projections can result in controversies and lack of enforcement that bring about temporary resettlement, land speculation, and creation of new risks ((Jha *et al*., 2010)(Ingram *et al*., 2006)).

Formal approaches to land use planning as a means of disaster risk management are often less appropriate for many rural areas in developing countries where traditional practices and land tenure systems operate. Similar restrictions are found in regard to slums and squatter settlements. Poverty and the lack of infrastructure and services increase the vulnerability of urban poor to adverse impacts from disasters and national governments and international agencies have had little success in reversing such trends. Most successful efforts to bring about reductions in exposure have been those that have been locally led and that build on successful local initiatives ((Satterthwaite *et al*., 2007)).

Land acquisition is another means for protecting property and people by relocating them away from hazardous areas ((Olshansky and Kartez, 1998)). Many jurisdictions have the power of eminent domain to purchase property but this is rarely used as a form of disaster risk reduction ((Godschalk *et al*., 2000)). Voluntary acquisition of land, for example, requires local authorities to purchase exposed properties, which in turn enables households to obtain less risky real estate elsewhere without suffering large economic losses in the process ((Handmer, 1987)). Given the large number and high value of exposed properties in coastal zones in developed countries such as the United States and Australia this buy out strategy is cost-prohibitive and thus, rarely used ((Anning and Dominey-Howes, 2009)). Similarly, voluntary acquisition schemes for developing countries are equally fraught with problems as people have strong ties to the land, and land is held communally in places like the Pacific Islands where community identity cannot be separated from the land to which its members belong ((Campbell, 2010b)). Land use planning alone, therefore, may not be successful as a singular strategy but when coupled with related policies such as tax incentives or disincentives, insurance, and drainage and sewage systems it could be effective ((Cheong, 2011; Yohe and Newmann, 1997)).

Ecosystem conservation offers long-term protection from climate extremes. The mitigation of soil erosion, landslides, waves, and storm surges are some of the ecosystem services to protect people and infrastructure from extreme events and disasters ((Sudmeier-Rieux, K., H. Masundire, A. Rizvi,S.Rietbergen (eds.), 2006)). The 2005 Asian tsunami, for example, attests to the utility of mangroves, coral reefs, and sand dunes in alleviating the influx of large waves to the shore ((Das and Vincent, 2009)). The use of dune management districts to protect property along developed shorelines has achieved success in many places along the U.S. eastern shore and elsewhere ((Nordstrom, 2000; Nordstrom, 2008)). While the extent of their protective ecosystem functions is still debated ((Gedan, K. B., M. L. Kirwan, E. Wolanski, E. B. Barbier,B.R.Silliman, 2011)), the merits of the ecosystem services in general are proven, and development of quantified models of the services is well under way ((Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. R. Cameron, K. M.A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf , R. Naidoo, T. H. Ricketts,M.R.Shaw, 2009)). These nonstructural measures are considered to be less intrusive and more sustainable, and the necessity for integrating engineering responses and vegetation barriers as responses to climate extremes have begun to be recognized ((Cheong, 2011; Francis, R.A. , S. Falconi, R. Nateghi, S.D. Guikema, in Ed,S.Cheong, 2011)).

5.2.5. Surplus and Storage of Resources

Communities may take a range of approaches to cope with disaster induced shortages. These include production of surpluses and their storage. And if these fail, rationing of food may occur. In pre-colonial times many communities produced food surpluses which enabled them to manage during periods of seasonal or disaster initiated disruptions to their food supplies. In Pacific Island communities food crops such as taro and breadfruit were often ensiled in leaf-lined pits, yams could be stored for several years in dry locations, and most communities maintained famine foods such as wild yams (dioscorea spp.), swamp taro (cyrtosperma spp.) and sago (metroxylon spp.) which were only harvested during times of food shortage ((Campbell, 2006)). The provision of disaster relief among other factors has seen these practices decline ((Campbell, 2010)). Stockpiling and prepositioning of emergency response equipment, materials, foods and pharmaceuticals and medical equipment is also an important form of disaster preparedness at the local level, especially for indigenous communities.

Rationing at the local level is often instituted at the level of households, particularly poor ones without the ability to accumulate wealth or surpluses, in the face of disaster induced declines in livelihoods. Most rationing takes place in response to food shortages and is for most poor communities, the first response to the disruption of livelihoods ((Baro and Deubel, 2006; Barrett, 2002; Devereux and Sabates-Wheeler, 2004; Walker, 1989)). In many cases increases in food prices force those with insufficient incomes to ration as well.

Rationing may be seen as the initial response to food shortages at or near the onset of a famine. However, in many cases rationing is needed on a seasonal basis. This rationing is done at the level of households and communities. When the shortage becomes too severe, households may reduce future security by eating seeds or selling livestock, followed by severe illness, starvation and death if the shortages persist. While climate change may alter the frequency and severity of droughts, the causes of famine are multi-factoral and often lie in social, economic and political processes in addition to climatic variability ((Bohle *et al.*, 1994; Sen, 1981; Wisner *et al.*, 2004)).

Food rationing is unusual in developed countries where most communities are not based on subsistence production and welfare systems and NGO agencies respond to needs of those with livelihood deficits. However, other forms of rationing do exist particularly in response to drought events. Reductions in water use can be achieved through a number of measures including: metering, rationing (fixed amounts, proportional reductions, or voluntary reductions), pressure reduction, leakage reduction, conservation devices, education, plumbing codes, market mechanisms (e.g. transferable quotas, tariffs, pricing) and water-use restrictions ((Froukh, 2001; Lund and Reed, 1995)).

Electricity supplies may also be disrupted by disaster events resulting in partial or total blackouts. Such events cause considerable disruption to other services, domestic customers and to businesses. Rose *et al.* ((Rose *et al.*, 2007)) show that many American businesses can be quite resilient in such circumstances adapting a variety of strategies including conserving energy, using alternative forms of energy, using alternative forms of generation, rescheduling activities to a future date or focussing on the low or no energy elements of the business operation. Rose and Liao ((Rose and Liao, 2005)) had similar findings for water supply disruption. Electricity rationing may also be required when low precipitation reduces hydroelectricity production, a possible scenario in some places under some climate projections ((Boyd and Ibarrarán, 2009; Vörösmarty *et al.*, 2000)). In some cases there may be competition among a range of sectors including industry, agriculture, electricity production and domestic water supply ((Vörösmarty *et al.*, 2000)) that may have to be addressed through rationing and other measures such as those listed above. However, using fossil fuels to generate electricity as an alternative to hydro production may be considered a maladaptive option.

Other elements that may be rationed as a result of natural hazards or disasters include medical and health services (often referred to as triage) where disasters may simultaneously cause large a spike in numbers requiring medical assistance and a reduction in medical facilities, equipment, pharmaceuticals and personnel. Triage is a process of classifying patients and prioritizes those with the greatest need and the highest likelihood of a positive outcome. From this perspective triage seeks to achieve the best results for the largest number of people ((Alexander, 2002) (Iserson and Moskop, 2007)).

5.2.6. Migration and other Population Movements

Natural disasters are linked with population mobility in a number of ways. Evacuations (see 5.2.2.) occur before, during and after some disaster events. Longer-term relocation of affected communities sometimes occurs. Relocations can be both temporary (a few weeks to months), or longer, in which case they become permanent. These different forms of population movements have quite different implications for the communities concerned. They may also be differentiated on the basis of whether the mobility is voluntary or forced and whether or not international borders are crossed. Most contemporary research views population mobility as a continuum from completely voluntary movements to completely forced migrations ((Laczko, 2009)).

Community relocation schemes are those in which whole communities are relocated to a new non-exposed site. Perry and Lindell ((Perry and Lindell, 1997)) examine one such instance in Allenville, Arizona. They developed a set of five principles for achieving positive outcomes in relocation projects: 1) The community to be relocated should be organised; 2) All potential relocatees should be involved in the relocation decision-making process; 3) Citizens must understand the multi-organisational context in which the relocation is to be conducted; 4) Special attention should be given to the social and personal needs of the relocatees; and 5) Social networks need to be preserved ((Perry and Lindell, 1997)). For many communities relocation is difficult, especially in those communities with communal land ownership. In the Pacific Islands, for example, relocation within one's own lands is least disruptive but leaving it completely is much more difficult, as is making land available for people who have been relocated ((Campbell, 2010b)).

Where climate change increases the marginality of livelihoods and settlements beyond a sustainable level, communities may be forced to migrate. This may be caused by changing mean conditions or through changes in extreme events. Extremes often serve as precipitating events ((Hugo, 1996)). Myers' ((Myers, 2002)) prediction that there would be as many as 200 million environmentally forced migrants by mid 21st century has been widely reported. Brown ((Brown, 2008)) provides a range of estimates from an increase of five to ten per cent over current migration flows under a favourable projection upwards to a figure that may exceed Myer's prediction under the worst case scenario. These efforts to quantify climate migration do not distinguish the climatic causes of migration which typically has many causative factors ((Hugo, 1996)). Many researchers have raised doubts about such a magnitude of migration and many consider that climate related migration may not necessary be a problem and indeed may be a positive adaptive response ((Barnett and Webber, 2009)).

These figures are global estimations and provide little insight into the likely local implications of such large-scale migratory patterns. Migration will have local effects, not only for the communities generating the migrants, but those communities where they may settle. Barnett and Webber (2009) also note that the less voluntary the migration choice is, the more disruptive it will become. In the context of dam construction, for example Hwang *et al.* ((Hwang *et al.*, 2007)) found that communities anticipating forced migration experienced stress. Hwang *et al.* ((Hwang *et al.*, 2010)) also found that forced migration directly led to increased levels of depression and the weakening of social safeguards in the relocation process. One outcome of climate change may be that entire communities may be required to relocate and in some cases, such as those living in atoll countries, the relocation may have to be international. It is likely that such relocation will have significant social, cultural and psychological impacts ((Campbell, 2010b)).

5.2.7. Emergency Assistance and Disaster Relief

Relief often is unsuitable or inappropriate because people affected by disasters are not completely helpless or passive ((Cuny, 1983)(De Ville de Groyet, 2000)). This view is sustained by commonplace definitions of disasters as situations where communities or even countries cannot cope without external assistance ((Cuny, 1983)). In some cases, relief serves to remove agency from disaster 'victims' so that 'ownership' of the event and control over the recovery phase is lost at the local level ((Hillhorst, 2002)).

It is important to realise that the first actors providing assistance during and after disasters are members of the affected community ((De Ville de Groyet, 2000)). In isolated communities such as those in outer islands, external assistance may be subject to considerable delay and self-help is an important element of response. Typically, emergency assistance and disaster relief in developed countries comes in the form of assistance from national and state/provincial level governments to local communities. For developing countries international relief is more commonly distributed, although quite often heavy costs also fall on developing country governments. In all disasters initial assistance comes from local sources ((Development Initiatives, 2009)). International relief may come from a range of sources including multilateral institutions (common actors are UNOCHA, UNDP, WHO and UNICEF), bilateral arrangements, the International Federation of Red Cross and Red Crescent Societies, and numerous NGOs such as Oxfam, Save the Children Fund and the like ((Beamon and Balcik, 2008)). The disaster relief process has become highly sophisticated and much broader in scope over the past two decades and includes such things as assistance in post-disaster assessment, food provision, water and sanitation, medical assistance and health services, household goods, temporary shelter, transport, tools and equipment, security, logistics, communications and community services ((Cahill, 2007)(Bynander *et al.*, 2005)).

Much disaster assistance takes place at the local level through local charities, kinship networks and local governments. There is also a considerable amount of relief that tends to be organised at more of a national and international scale than local scale, although distribution and use of relief occur at the local level. From this perspective it is vital to understand what is locally appropriate in terms of the type of relief provided, and how it is distributed ((Kovác and Spens, 2007)). Similarly, local resources and capacities should be utilised as much as possible (Beamon and Baclik, 2008). There has also been a recent trend towards international humanitarian organisations working with local partners, although this can result in the imposition of external cultural values resulting in resentment or resistance ((Hillhorst, 2002)).

While relief is often a critically important strategy for coping, there are problems associated with it. Relief can undermine local coping capacities and reduce resilience and sustainability ((Susman *et al.*, 1983; Waddell, 1989)) and it may reinforce the status quo that was characterized by vulnerability ((O'Keefe *et al.*, 1976)). Relief is often inequitably distributed and in some disasters there is insufficient relief. Corruption is also a factor in some disaster relief operations with local elites often benefiting more than others ((Pelling and Dill, 2010)).

Not all disasters engender the same response as local communities receive different levels of assistance. For example, those people most affected by a small event can suffer just as much as a globally publicised big event but are often overlooked by relief agencies. Fast onset and unusual disasters such as tsunamis generate much more public interest and contributions from governments, NGOs, and the public, sometimes referred to as the CNN factor ((Schmid, 1998){{}}). Disasters that are overshadowed by other newsworthy or media events, such as coverage of the Olympic Games, are often characterised by lower levels of relief support ((Eisensee and Stromberg, 2007)). Where there is widespread media coverage, NGOs and governments are often pressured to respond quickly with the possibility of an oversupply of relief and personnel. This has worsened in recent times when reporters are ‘parachuted’ into disaster sites often in advance of relief teams (who have more than a camera and satellite transmitter to transport and distribute) but who have little understanding of the contextual factors that often underlie vulnerability to disasters ((Silk, 2000)). Such media coverage often perpetrates disaster myths such as the prevalence of looting, helplessness and social collapse putting pressure on interveners to select military options for relief when humanitarian assistance would be more helpful ((Tierney *et al.*, 2006)).

Relief is politically more appealing than disaster risk reduction (DRR) ((Seck, 2007)) and it often gains much greater political support and funding than measures that would help offset the need for it in the first place. Providing relief reflects well on politicians (both in donor and recipient countries) who are seen to be caring, and taking action, and responding to public demand ((Eisensee and Stromberg, 2007)).

Major shares of the costs of disaster relief and recovery still fall on the governments of disaster affected countries. Bilateral relief is often tied and is limited to materials from donor countries and most relief is subject to relatively strict criteria to reduce perceived levels of corruption. In both of these cases flexibility is heavily restricted. Relief can also produce local economic distortions such as causing shops to lose business as the market becomes flooded with relief supplies. At the same time, there is the view that disaster relief can create a culture of dependency and expectation at the local level ((Burby, 2006)), where disaster relief becomes viewed as an entitlement program as local communities are not forced to bear the responsibility for their own locational choices, land use, and lack of mitigation practices.

5.3. Community-Based Risk Management in a Changing Climate

Community-based risk management has traditionally dealt with climate events without considering the long-term trajectories presented by a changing climate. This section provides examples of adaptations to disaster risk and how such proactive behaviors at the community level by local government and NGOs can provide guidance for reducing the longer term impacts of climate change. Although reacting to extreme events and their impacts is important, it is crucial to focus on building the resilience of communities, cities and sectors in order to ameliorate the impacts of extreme events now and into the future.

5.3.1. Local Climate Extremes

Local communities routinely experience natural hazards many from climate-related events (see Chapter 3). Drought has affected local communities from Africa to the Americas, to Australia and New Zealand. Tropical and extra-tropical windstorms are seasonal events for many regions. A compendium of extreme hazard events related to climate illustrates the pervasive nature of hazards on communities, according to one data source (see Table 5-2). All regions and many of the local communities within them have experienced a disaster event (defined by thresholds of more than 10 people killed or 100 affected, or a call for international assistance, or a declaration of a state of emergency) during the past decade. Flooding and windstorms (cyclones and hurricanes) are among the most prevalent, with the impacts measured in economic losses as well as human losses (see Table 5-3). However, local communities routinely experience hazards that do not rise to the same level of impact as a disaster. These include snow and ice events; severe storms, flooding, and hail events. Heat waves and wildfires are more frequent events in the northern latitudes ((Alcamo *et al*., 2007); (Field *et al*., 2007)). More intense rainfall producing flooding and mud slides in mountainous are becoming the norm rather than the exception in many parts of the world ((Solomon *et al*., 2007)). Communities affected by drought persist in Africa, India, and China. Coastal communities worldwide are experiencing more erosion due to stronger storms. What is now different is that these hazards are relatively new for many communities. For example, Hurricane Catarina, the first South Atlantic hurricane which made landfall as a category 1 storm just north of Porto Alegre, Brazil, in March 2004 ((McTaggart-Cowan *et al*., 2006)), the region's first local experience with a hurricane.

[INSERT TABLE 5-2 HERE:
Table 5-2: Local experience with climate extreme hazards based on number of reported disasters, 1999-2008.]

[INSERT TABLE 5-3 HERE:
Table 5-3: Top five climate extreme hazards events, 1950-2009.]

5.3.2. Assessing Coping in Light of Disaster Risk Management: What Leads to Proactive Behaviors?

Capacity investments necessarily involve decisions based on prior disaster experiences and future disaster expectations, including those related to emergency response and disaster recovery. Birkland ((Birkland, 1997), Pulwarty and Melis ((Pulwarty and Melis, 2001)) and others, have identified some of the physical and social characteristics that allow for the prior adoption of effective partnerships and implementation practices during events. These include the occurrence of previous strong focusing events (such as catastrophic extreme events) that generate significant public interest and the personal attention of key leaders, a social basis for cooperation including close inter-jurisdictional partnerships, and the existence of a supported collaborative framework between research and management. Although loss of life from natural hazards has been declining, the property and livelihood losses from those causes have been increasing. Factors conditioning this outcome have been be summed up by Burton *et al.* ((Burton *et al*., 2001)) as "knowing better and losing even more". For instance researchers have understood the consequences of a major hurricane hitting New Orleans with a fairly detailed understanding of planning and response needs. This knowledge appears to have been ignored at all levels of government including the local level ((Kates *et al*., 2006)). Burton *et al*. ((Burton *et al*., 2001)) offer four explanations for why such conditions exist from an information standpoint: 1) knowledge continues to be flawed by areas of ignorance; 2) knowledge is available but not used effectively; 3) knowledge is used effectively but takes a long time to have an impact; and 4) knowledge is used effectively in some respects but is overwhelmed by increases in vulnerability and in population, wealth, and poverty.

The impacts and changes that some focusing events engender can only defined retrospectively ((Barton, 1969; Barton, 2005; Fritz, 1961; Turner, 1978)). For example, a 30-year drought-induced famine ultimately becomes defined as a multiple disaster. Such a disaster exists in social time only when changing historical conditions over decades have been collectively reconstructed to define them as acute. Individuals can make choices to reduce their risk but social relations, context, and certain structural features of the society in which they live and work mediate these choices and their effects. A growing acknowledgement that aid cannot cover more than a small fraction of the costs of disasters is leading to new approaches, priorities and institutional configurations. The realization that dealing with risk and insecurity is a central part of how poor people develop their livelihood strategies has begun to position disaster mitigation and preparedness within many poverty alleviation agendas ((Olshansky and Kartez, 1998)(Cuny, 1983; UNISDR, 2009)). A number of long-standing challenges remain as the larger and looser coalitions of interests that sometimes emerge after great catastrophes rarely last long enough to sustain the kind of efforts needed to reduce hazards and disaster risk.

Another pro-active behavior is the use of spatial hazard information by planners. However, such us is likely only if the information is clearly mapped, comes from an authoritative source and provides specific guidelines for action and ease of implementation, and the community is provided with evidence that the approaches have worked in other places ((Olshansky and Kartez, 1998)). Berke and Beatley ((Berke and Beatley, 1992)) examined a range of hazard mitigation measures and ranked them according to effectiveness and ease of enforcement. The most effective measures are land acquisition, density reduction, clustering of development, building codes for new construction, and mandatory retrofit of existing structures. The high costs land acquisition programs can make them unattractive to small communities (see 5.2.4). There has been limited systematic scientific characterization of the ways in which different hazard agents vary in their threats and characteristics and, thus, requiring different pre-impact interventions and post-impact responses by households, businesses, and community hazard management organizations.

Short-term risk reduction strategies can actually produce greater vulnerability to future events as shown in diverse contexts such as ENSO-related impacts in Latin America, induced development below dams or levees in the U.S., and flooding in the UK ((Bowden, 1981)(Berube and Katz, 2005; Penning-Rowsell *et al.*, 2006; Pulwarty *et al.*, 2004)). One important finding about community protection works such as dams and levees is that they are commonly misperceived as providing complete protection, so they actually increase development—and thus vulnerability—in hazard-prone areas ((Burby, 2006)). A more general statement of this proposition is found in the safe development paradox in which increased safety induces increased development leading to increased losses. The conflicting policy goals of rapid recovery, safety, betterment, and equity and their relative strengths and weaknesses largely reflect experience with large disasters in other places and times. The actual decisions and rebuilding undertaken to date clearly demonstrate the rush by government at all levels and the residents themselves to rebuild the familiar ((Kates *et al.*, 2006)). Similarly, in drought prone areas provision of assured water supplies encourages the development of intensive agricultural systems – and for that matter, domestic water use habits – that are poorly suited to the inherent variability of supply and will be even more so in areas projected to become increasingly arid in a changing climate.

Burby and May *et al.* ((Burby *et al.*, 1997)) have found evidence for some communities that previous occurrence of a disaster did not have a strong effect on the number of hazard mitigation techniques subsequently employed. Agendas are unstable over time and disasters can affect them by serving as focusing events ((Anderson, 1994; Birkland, 1997; Kingdon, 1984)), concentrating public and official attention for a certain time, resulting in a window of opportunity.

On the other hand, extreme events have been identified as offering “windows of opportunity” for including both retrofitting and long term risk reduction plans, such as for climate change adaptation, after particularly severe or visible events such as Hurricane Katrina or severe, sustained drought. A policy window opens when the opportunity arises to change policy direction and is thus an important part of agenda setting ((Anderson, 1994; Kingdon, 1984)). Policy windows can be created by triggering or focusing events, such as disasters, as well as by changes in government and shifts in public opinion. Immediately following a disaster, the political climate may be conducive to much needed legal, economic and social change which can begin to reduce structural vulnerabilities, for example in such areas as mainstreaming gender issues, land reform, skills development, employment, housing and social solidarity. The assumptions behind the utility of policy windows are that: 1) new awareness of risks after a disaster leads to broad consensus; 2) development and humanitarian agencies are 'reminded' of disaster risks; and 3) enhanced political will and resources become available ((Christoplos, 2006; Michaels *et al.*, 2006)). However, during the post-recovery phase, reconstruction requires weighing, prioritizing, and sequencing of policy programming, and there are multiple sometimes competing mainstreaming agendas for most decision-makers and operational actors to digest with attendant lobbying for resources for various actions. The most significant is the pressure to quickly return to conditions prior to the event rather than incorporate longer term development policies ((Christoplos, 2006; Kates *et al.*, 2006)). How long such a window will stay open or precisely what factors will make it close under a given set of conditions is not well-known, even though 3-6 months has been recognized in specific cases ((Kates *et al.*, 2006)).

The active participation of women has been shown to increase the effectiveness of prevention, disaster relief, reconstruction and transformation of communities ((Enarson and Morrow, 1997)) (see Box 5-4). There is also research which suggests that children can be effective conveyors of risk information and become active agents for building preparedness and resilience to disasters and climate change, but such a role has been neglected or underestimated ((Bartlett, 2008; Manyena *et al.*, 2008; Mitchell *et al.*, 2008; Peek, 2008)).

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Box 5-4. The Role of Women in Proactive Behavior

Women's involvement in running shelters and processing food was crucial to the recovery of families and communities after Hurricane Mitch hit Honduras. A third of the shelters were run by women, and this figure rose to 42% in the capital. The municipality of La Masica in Honduras, with a mostly rural population of 24,336 people, stands out in the aftermath of Mitch because, unlike other municipalities in the northern Atlanta Department, it reported no mortality. This outcome can be directly attributed to a process of community emergency preparedness that began about six months prior to the disaster, Gender lectures were given and, consequently, the community decided that men and women should participate equally in all hazard management activities. When Mitch struck, the municipality was prepared and vacated the area promptly, thus avoiding deaths. Women participated actively in all relief operations. They went on rescue missions, rehabilitated local infrastructure (such as schools), and along with men, distributed food. They also took over from men who had abandoned the task of continuous monitoring of the early warning system. The experience shows that preparedness is an important step in saving lives. The incorporation of women from the start, on an equal footing with men, contributed to the success in saving lives ((Enarson and Morrow, 1997))**.**

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5.3.3. Basic Development and Human Security

The physical trends and changing patterns in the climate are projected to increase in the future in terms of intensity and frequency leading to more frequent and severe climatic events (see Chapter 3). Developing countries including LDCs and SIDS are generally characterized by certain socio-economic trends high rates of population growth (especially in hazard prone areas); urbanization; food insecurity; high levels of poverty; conflicts; and mismanagement of natural resources) that render them more vulnerable to the impacts of climate change (Chapter 2). For the LDCs in Africa and Asia, climate change is expected to result in flooding of low-lying coastal areas, increased water scarcity, decline in agricultural yields and fisheries resources, and loss of biological resources (Osman-Elasha and Downing, 2007)). People exposed to the most severe climate-related hazards are often those least able to cope with the associated impacts, due to their limited adaptive capacity; a situation that is likely to impose additional threats to economic development, efforts to reduce poverty and achieve the Millennium Development Goals ((Stern, 2007; UNDP, 2007)). Similar to droughts, floods have a significant impact on African development as recurrent floods in some countries are linked with El Niño-Southern Oscillation (ENSO) events resulting in major economic and human losses in e.g. Mozambique ((Mirza, 2003); (Obasi, 2005)) and Somalia ((Kabat *et al*., 2002)). The impacts of droughts and floods are often further exacerbated by health problems, such as diarrhea, cholera and malaria ((Kabat *et al*., 2002)).

Climate change effects will not happen in hypothetical scenarios, but in local territories where many hazards already occur and where ecosystems and communities are already facing multiple risks. It is possible that some new and unknown hazards may appear, but in most cases climate change will make the existing hazards more complex and harmful ((Parry *et al*., 2007; Solomon *et al*., 2007)). For example, in places already affected by crisis situations such as political violence producing trans-border refugees as well as internally displaced people, climate change may exacerbate the situation. Climate change causes environmental stress and is therefore is a potential cause of conflict along with local unsustainable behavior ((Osman-Elasha, 2008)). Environmental stress feeds the tensions between communities as they compete for land to support their livelihoods ((Barnett, 2001; Kates, 2000; Osman-Elasha and El Sanjak, 2009)). Such complex relations can easily lead to a vicious circle of deprivation with more and more displaced people, new and added pressures on the environment, leading to its deterioration and ultimately the destruction of livelihoods, and increasing conflict.

The effective reduction of vulnerabilities to current natural hazards and to climate change requires coordination across different levels and sectors and the involvement of a broad range of stakeholders beginning at the local level ((Devereux and Coll-Black, 2007; DFID, 2006; UNISDR, 2004)). To strengthen the link between disaster risk management and adaptation to climate change, it is important to understand when, and at what level, coordination is required, and who should take the lead ((Mitchell and Van Aalst, 2008)). Many adaptation strategies, such as large-scale agriculture, irrigation and hydroelectric development, will benefit large groups or the national interests but they may harm local, indigenous and poor populations ((Kates, 2000)(Kates, 2000)). Therefore, any new disaster reduction or climate change adaptation strategies must be build on strengthening local actors and enhancing their livelihoods ((Osman-Elasha, 2006a)). It is equally important to identify the differentiated social impacts of climate change based on gender, age, disability, ethnicity, geographical location, livelihood, and migrant status ((Tanner and Mitchell, 2008)). The problem is in identifying those adaptations that favor these most vulnerable groups, and to address these problems using an integrated management approach, with different stakeholders ((Sperling and Szekely, 2005)). Win-win solutions are unlikely with climate change, as there will always be winners and losers from extreme events ((Adger, 2001)). It is increasingly recognized that adaptation and DRR must be integral components of development planning and implementation, to increase sustainability ((Thomalla *et al*., 2006)). In other words, adaptation and DRR should be mainstreamed into national development plans, poverty reduction strategies, sectoral policies and other development tools and techniques ((UNDP, 2007)). Efforts to forge greater and more equitable capacity at the local scale have to be supported by policies at the national level to increase the ability of local institutions and communities to cope with present and future risks from climate-sensitive hazards ((Tearfund., 2006)).

5.3.4. Recovery and Reconstruction Post Event

Recovery and reconstruction include actions that seek to establish ‘everyday life’ of the community affected by disaster ((Hewitt, 1997)). Often reconstruction enables communities to return to the same conditions that existed prior to the disaster, and in so doing create the potential for further similar losses, thus reproducing the same exposure that resulted in disaster in the first place ((Jha *et al*., 2010)). There are a number of obstacles to effective and timely reconstruction including lack of labour, lack of capacity among local construction companies, material shortages, resolution of land tenure considerations, and insufficiency of funds ((Keraminiyage *et al*., 2008)). While there is urgency to have people re-housed and livelihoods re-established, long-term benefits may be gained through carefully implemented reconstruction ((Hallegatte and Dumas, 2009)(Hallegatte, 2008)).

Recovery and reconstruction (especially housing rehabilitation and rebuilding) are among the more contentious elements of disaster response. One of the major issues surrounding recovery in the scientific literature is the lack of clarity between recovery as a process and recovery as an outcome. The former emphasizes betterment processes where pre-existing vulnerability issues are addressed. The latter focuses on the material manifestation of recovery such as building houses or infrastructure. Often following large disasters large-scale top down programmes result in rebuilding houses but failing to provide homes ((Petal *et al*., 2008)). Moreover, haste in reconstruction, while achieving short-term objectives, often results in unsustainable outcomes and increasing vulnerability ((Ingram *et al*., 2006)I(Ingram *et al*., 2006)). As seen in the aftermath of Hurricane Katrina, there are measureable local disparities in recovery, leading to questions of recovery for whom and recovery to what ((Curtis *et al*., 2010; Finch *et al*., 2010; Stevenson *et al*., 2010)).

Most reporting on recovery and reconstruction has tended to focus on housing and the so-called lifelines of infrastructure: electricity, water supply and transport links. However, equally important, if indeed not more so, is the rehabilitation of livelihoods, especially in developing countries. Accordingly, it is important to include those climate related disaster events, such as droughts, that don't just destroy the built environment in evaluating recovery and reconstruction. Indeed post-disaster recovery that takes the need to re-establish livelihoods, in particular sustainable, livelihoods is an important aspect of disaster risk reduction and development ((Nakagawa and Shaw, 2004)).

As with relief, major problems occur where planning and implementation of recovery and reconstruction is taken from the hands of the local communities concerned. Moreover, the use of inappropriate (culturally, socially or environmentally) materials and techniques may render rebuilt houses as unsuitable for their occupants ((Jha *et al*., 2010)). However, as Davidson *et al*. ((Davidson *et al*., 2007)) found, this is often the case and results in local community members having little involvement in decision making and being; instead they are used to provide labor. It is also important to acknowledge that post-disaster recovery often does not reach all community members and in many recovery programmes, the most vulnerable, those who have suffered the greatest losses, often do not recover from disasters, and endure long-term hardship (Wisner *et al*., 2004: 358).

Post-disaster rehabilitation provides a critical opportunity for reducing risk in the face of further events. In reconstructing livelihoods damaged or destroyed by disaster it is important to take into account the diversity of livelihoods in many communities, to work with community members to develop strategies and to work towards producing sustainable livelihoods that are likely to be more resilient in the face of future events ((Pomeroy *et al*., 2006)).

5.3.5. Components of Risk Management and Climate Adaptation

There are many different components to risk management and climate adaptation. Each presents a unique set of opportunities and challenges for disaster risk management and climate adaptation. This section covers some of the most important locally-based components including anticipating risks, communicating risk information, empowerment and leadership, social drivers, integrating risk knowledge into practice, and local government initiatives and practices.

5*.3.5.1. Anticipate Risks in a Climate Change Context*

Climate change presents a challenge for existing good practice of disaster risk reduction because it introduces changes in climate risks over time. In order to anticipate the risks and surprise associated with climate change there are two emerging responses at the local level. The first is to integrate information about changing climate risks into disaster planning and the second is to focus on community-based adaptation (CBA), where the effected community helps to define solutions for managing risks whilst considering climate change.

Contextualizing disaster response within a climate change continuum requires information and knowledge about both slow and fast onset events ((Ensor and Berger, 2009)) . Weather information is critical for responding to flashfloods and cyclones, seasonal climate information can help to respond to drought and above normal rainfall predictions and longer-term decadal forecasts can help to understand shifts in the seasons. Although early warning systems that draw on weather information have been used to manage disasters, there has not been much experience in using seasonal climate forecast information to prepare for extreme events although there is experience on using seasonal forecasts as a means for dealing with annual variability that is expected to shift with climate change (see

Box 5-5) ((Hellmuth *et al.*, 2007)(Patt *et al.*, 2009)). A response by the IFRC in the West/Central Africa Zone (WCAZ) shows how they issued the first emergency appeal based on a seasonal forecast of expected intense rainfall and pre-positioned relief items, developed flood contingency plans and launched pre-emergency funding requests (((IFRC),International Federation of the Red Cross and Red Crescent Societies, 2009; Suarez, 2009)). Setting up plans in advance enabled communication systems to be strengthened before the extreme event struck, so that when it did information was passed from national headquarters to regional focal points, to the districts, to community leaders and on to communities (((IFRC),International Federation of the Red Cross and Red Crescent Societies, 2009)).

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Box 5-5. Case Study – Small-Scale Farmers Adapting to Climate Change (Northern Cape, South Africa): Taking Collective Action to Improve Livelihoods Strategies

The Northern Cape Province, South Africa, is a harsh landscape, with frequent and severe droughts and extreme conditions for the people, animals and plants living there. This has long had a negative impact on small-scale rooibos farmers living in some of the more marginal production areas. Rooibos is an indigenous crop that is well adapted to the prevailing hot, dry summer conditions, but is sensitive to prolonged drought. Rooibos tea has become well-accepted on world markets, but this success has brought little improvement to marginalised small-scale producers.

In 2001 a small group of farmers decided to take collaborative action to improve their livelihoods and founded the Heiveld Co-operative Ltd. Initially established as a trading co-operative to help the farmers produce and market their tea jointly, it subsequently became apparent that the local organisation was also an important vehicle for social change in the wider community ((Oettlé *et al.*, 2004)). The Heiveld became a repository and source of local and scientific knowledge related to sustainable rooibos production.

Adaptation that builds on local knowledge, responds to local conditions and is driven by the positive energy of affected communities creates sustained resilience in the face of environmental, economic and social change. Local capacities have been strengthened, and the local organisation (the Heiveld Co-operative) has been able to expand its networks – an important and necessary aspect of increasing resilience in challenging times.

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In order to strengthen the integration of climate information at the local level, better systems are necessary. A systematic restructuring is needed in order for the humanitarian community to absorb and act on climate information that is currently available ((Suarez, 2009)). Part of the challenge is in translating output from climate change scenarios and seasonal climate forecasts into decisions on whether humanitarian organizations should act or not. Climate information has a complex set of data including figures, tables and technical statements, yet at the local level organisations determine their response if probability of the hazard is high enough and if too many people are at risk. Communication strategies are needed to ensure that climate information about impending threats can be synthesized and translated into decisions and actions ((Suarez, 2009)).

The second response to strengthening community-based disaster risk management in a climate change context has been to focus on community-based adaptation (CBA), where the community is involved in deciding how they want to prepare for climate risks and coordinate community action to achieve adaptation to climate change ((Ebi, 2008)). Part of this entails community risk assessment (CRA) for climate change adaptation that assesses the hazards, vulnerabilities and capacities of the community ((Van Aalst *et al.*, 2008)), which has also been called community based disaster preparedness (CBDP) among other names ((Allen, 2006)). The intention is to foster active participation in collecting information that is rooted in the communities and enables affected people to participate in their own recovery through enhancing resilience by strengthening social-institutional measures including social relations ((Allen, 2006)). In assessing short and long term climate risks, the input from and needs of vulnerable groups are often excluded, which is clearly seen in the NAPAs where the urban poor seldom feature ((Douglas *et al.*, 2009)). The tools for engaging vulnerable groups in the process include transect walks and risk maps that capture the climate related hazards and risks ((Van Aalst *et al.*, 2008)) and storylines about possible future climate change impacts ((Ebi, 2008)), although these tools often require input from participants external to the community with long-term climate information ((Van Aalst *et al.*, 2008)).

The challenges in using community-based adaptation approaches include the challenge of scaling up information, the fact that it is resource-intensive ((Van Aalst *et al.*, 2008; Van Aalst *et al.*, 2008)) and that unintended disempowerment does occur at times ((Allen, 2006)). The integration of climate change information increases this challenge as it introduces an additional layer of uncertainty ((Allen, 2006)) and may conflict with the principle of keeping CBA simple ((Van Aalst *et al.*, 2008)). There is little evidence that secondary data on climate change has been used in CBA, partly because of the challenge of limited access to downscaled climate change scenarios relevant at the local level ((Ziervogel and Zermoglio, 2009)) and because of the uncertainty of projections.

Examples of CBA illustrate some of the processes involved. In northern Bangladesh, a Practical Action flooding adaptation project helped to establish early warning committees within villages that linked to organizations outside the community, with which they did not usually interact and that have historically blocked collective action and resource distribution ((Ensor and Berger, 2009)). Through this revised governance structure the building of small roads, digging culverts and planting trees to alleviate flood impacts was facilitated. In Portland, Oregon, the City Repair project engaged a range of actors to reduce the impact of urban heat islands through engaging neighborhoods and linking them to experts to install green roofs, urban vegetation and fountains that simultaneously increased a sense of ownership in the improvements ((Ebi, 2008)(Ebi, 2008)). In the Philippines, the CBDP approach enabled a deeper understanding of local-specific vulnerability than previous disaster management contexts, which they argue is critical because of the diverse impacts of climate change as compared to isolated disaster events ((Allen, 2006)). However, these community-based approaches should be viewed as part of a wider system that addresses multiple scales.

Under climate change, CBA responses are likely to be beneficial and need increased support). The need for coordinated collective action was seen in Kampala, where land cover change and changing climate is increasing the frequency and severity of urban flooding ((Douglas *et al.*, 2009)). Existing activities were uncoordinated although some collective action was undertaken to clear drainage channels. However, residents felt that much could be done to adapt to frequent flooding including increasing awareness of roles and responsibilities in averting floods, improving the drainage system, garbage and solid waste disposal as well as strengthening the building inspection unit and enforcing bylaws on the construction of houses and sanitation facilities. Similarly, in Accra, residents felt that municipal laws on planning and urban design need to be enforced suggesting that strong links are needed between community responses and municipal responses.

5.3.5.2. Communicating Disaster Risk

Both anticipating and responding to risk entails communications between communities, public officials, and experts (see 5.2.1). However, communicating the extreme impacts of climate change presents an important and difficult challenge ((Moser and Dilling, 2007)). A burgeoning field of research explores the barriers to communicating the impacts of climate change to motivate constructive behaviors and policy choices ((Frumkin and McMichael, 2008)). Research has shown that when delivering messages, those targeted to specific audiences are more likely to be effective ((Maibach *et al.*, 2008)). In addition, communication is likely to be more effective when the information regarding risk does not exceed the capacity for coping and therefore galvanizes resilience ((Fritze *et al.*, 2008)). Some research has suggested that a focus on personal risk of specific damages of climate change is a central element in motivating interest and behavior change ((Leiserowitz, 2007)). In addition, indicating threats to future generations may generate more concern than mentioning other climate change impacts ((Maibach *et al.*, 2008)(Maibach *et al.*, 2008)).

The characteristics of messages within risk communications that have a significant impact on local adoption of adjustments involve information quality (specificity, consistency, and source certainty) and information reinforcement (number of warnings) (; (Mileti and O'Brien, 1992; Mileti and Fitzpatrick, 1993; O'Brien and Mileti, 1992)). As used here, the term *risk communication* refers to intentional efforts on the part of one or more sources (e.g., international agencies, national governments, local government) to provide information about hazards and hazard adjustments through a variety of channels to different audience segments (e.g., the general public, specific at-risk communities). Researchers have long recognized different sources as being peers (friends, relatives, neighbors, and coworkers), news media, and/or authorities ((Drabek, 1986)). These sources systematically differ in terms of such characteristics as perceived expertise, trustworthiness, and protection responsibility ((Lindell and Perry, 1992; Lindell and Whitney, 2000; Pulwarty, 2007)). Risk area residents use channels for different purposes: the internet, radio and television are useful for immediate updates; meetings are useful for clarifying questions; and newspapers and brochures are useful for retaining information that might be needed later.

Risk messages also vary in threat specificity, guidance specificity, repetition, consistency, certainty, clarity, accuracy, and sufficiency ((Lindell and Perry, 2004; Mileti and Sorensen, 1990; Mileti and Peek, 2002)). The need to understand the usability of scientific information, especially at the local level, has received much attention from a communications perspective but little from an organizational perspective. There has been little systematic investigation, for example, on message effectiveness in prompting action based on differing characteristics such as the precision of message dissemination, penetration into normal activities, message specificity, message distortion, rate of dissemination over time, receiver characteristics, sender requirements, and feedback ((Lindell and Perry, 1992; NRC (National Research Council), 2006)). Receiver characteristics include previous hazard experience, preexisting beliefs about the hazard and protective actions, and personality traits. In addition, demographic characteristics—such as gender, age, education, income, ethnicity, marital status, and family size play strong roles. Within several countries (Lesotho, Mozambique and Swaziland) it was found that timely issuance remains a key weakness in climate information systems especially for communication passed on to communities from the national early warning units. There was also too much reliance on one-way devices for communication (such as the radio), which were felt to be inadequate for agricultural applications (for example, farmers are not able to ask further questions regarding the information provided) ((Ziervogel, 2004)). Within many rural communities, low bandwidth and poor computing infrastructure pose serious constraints to risk message receipt.

The degree of acceptability of information and trust in the providers, dictate the context of communicating climate information (see Box 5-6). Lindell and Perry ((Lindell and Perry, 2004)4) summarized the available research as indicating message effects include pre-decisional processes (reception, attention, and comprehension). Several studies have identified the characteristics of pre-decisional practices that lead to effective communication over the long-term ((Cutter, 2001; Fischoff, 1992; Pulwarty, 2007)). These include: 1) Understanding of the goals, objectives, and constraints of communities in the target system; 2) Mapping practical pathways to different outcomes can be carried out as a co-production strategy among research, extension and farmer communities; 3) Bringing the delivery persons (e.g. extension personnel), research community etc.) to an understanding of what has to be done to translate current information into usable information; 4) Interacting with actual and potential users to better understand informational needs, desired formats of information, timeliness of delivery etc.; 5) Assessing impediments and opportunities to the flow of information including issues of credibility, legitimacy, compatibility (appropriate scale, content, match with existing practice) and acceptability; and 6) Relying on existing stakeholders' networks and organizations to disseminate and assess climate information and forecasts.

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Box 5-6. Successful Communication of Local Risk-Based Climate Information

The following questions have been identified as shaping the successful communication of risk-based climate information ((Ascher, 1978; Fischoff, 1992; Pulwarty, 2003)).

What do people already know and believe about the risks being posed?
What has been the past experience/outcomes of information use?
Is the new information *relevant* for decisions in the particular community?
Are the sources/providers of information *credible* to the intended user?
Are practitioners (e.g. farmers) *receptive* to the information and to research?
Is the information *accessible* to the decision maker?
Is the information *compatible* with existing decision models e.g. for farming practice?

Does the community (or individuals in the community) have the *capacity* to use information?

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Communications that include social, interpersonal, physical environmental, and policy factors can foster civic engagement and social change fundamental to reducing risk ((Brulle, 2010). A participatory approach highlights the need for two-way communication that engenders credibility, trust and cooperation ((NRC (National Research Council), 1989)(Frumkin and McMichael, 2008)), which are especially important in high-stress situations such as extreme impacts of climate change ((NRC (National Research Council), 1989)). For example, participatory video production is effective in communicating the extreme impacts of climate change ((Suarez *et al.*, 2008)). Participatory video involves a community or group in creating their own videos through story-boarding and production ((Lunch, N. and Lunch, C., 2006)). Such projects are traditionally used in contexts, such as poor communities, where there are constraints to accurate climate information ((Patt and Gawa, 2002)). Engaging with community leaders or opinions leaders in accessing social networks through which to distribute information is another approach, traditionally used by health educators but also applicable to the translation of climate risks in a community context ((Maibach *et al.*, 2008)). These types of communication projects can motivate community action necessary to promote preparedness ((Jacobs *et al.*, 2009; Semenza, 2005)).

Visualizing methods such as mapping, cartographic animations, and graphic representations are also used to engage with stakeholders who may be impacted by extreme events ((Shaw *et al.*, 2009)). Many programs are developing ways to use visualizations to help decision-makers adapt to a changing environment, suggesting that such tools can increase climate literacy ((Niepold *et al.*, 2008)). Visualizations can be powerful tools, but issues of validity, subjectivity, and interpretation must be seriously considered in such work ((Nicholson-Cole, 2004)). These communications are most effective when they take local experiences or points of view and locally-relevant places into account ((O'Neill and Ebi, 2009)). Little evaluation has been done of visualization projects, therefore leaving a gap in understanding of how to most effectively communicate future risks of extreme events.

Part of the research gap regarding communication stems from the lack of communication projects that can be tested and shown to affect preparedness. On the most basic level, there is considerable understanding of the information needed for preparing for disasters, but less specific understanding of what information is necessary to generate community preparedness for climate change ((Fischhoff, 2007)). As observed by Finan ((Finan and Nelson, 2001)), the very discussion of climate forecasts and projections within potentially impacted communities has served as a vehicle for democratizing the drought discourse in Ceará (Northeast Brazil). Developing a seamless continuum across emergency responses, preparedness, and coping and adaptation requires insight into the demands that different types of disasters will place upon the community and the need to perform basic emergency functions--pre-event assessments, proactive hazards mitigation, incident management ((Lindell and Perry, 1996)). Preparing for short-term disasters enhances the capacity to adapt to longer term climate change.

5.3.5.3. Community Empowerment and Leadership

A critical factor in community based disaster risk reduction is that community members are empowered to take control of the processes involved. Marginalization ((Adger and Kelly, 1999); (Polack, 2008)(Mustafa, 1998)) and disempowerment ((Hewitt, 1997); (Mustafa, 1998)) are critical factors in creating vulnerability and efforts to reduce these characteristics play an important role in building resilient communities. Empowerment refers to giving community members control over their lives with support from outside ((Sagala *et al.*, 2009)). This requires external facilitators to respect community structures, traditional and local knowledge systems, to assist but not take a dominating role, to share knowledge and to learn from community members ((Petal *et al.*, 2008)). A key element in empowering communities is building trust between the community and the external facilitators ((Sagala *et al.*, 2009)). It is also important to note that communities have choices from a range of disaster management options ((Mercer *et al.*, 2008)). Empowerment in community based disaster risk management may also be applied to groups within communities whose voice may otherwise not be heard or who are in greater positions of vulnerability ((Wisner *et al.*, 2004)). These include women ((Bari, 1998); (Clifton and Gell, 2001); (Polack, 2008)(Wiest *et al.*, 1994)) and disabled people ((Wisner, 2002)).

Another key element of empowerment is ownership of the issue ((Buvinić *et al*., 1999)). This applies to all aspects of disaster management, from the ownership of a disaster itself so that the community has control of relief and reconstruction, to a local project to improve preparedness. Empowerment and ownership ensure that local needs are met, that community cohesion is sustained and a greater chance of success of the disaster management process.

5.3.5.4. Social Drivers

Localized social norms, social capital, and social networks shape behaviors and actions before, during, and after extreme events. Each of these factors both operates on their own and in some cases also intersects with the others. As vulnerability to disasters and climate change is socially-constructed (Chapter 2) ((Adger and Kelly, 1999)), the breakdown of collective action often leads to increased vulnerability. For example, coastal Northern Vietnam's institutional breakdown due to its economic transition has led to greater vulnerability to climate extremes ((Adger, 1999)).

Social norms are rules and patterns of behavior that reflect expectations of a particular social group ((Horne, 2001)). Norms structure many different kinds of action regarding climate change ((Pettenger, 2007)). Norms are embedded in formal institutional responses, as well as to smaller, informal groups that encounter disasters ((Raschky, 2008)). Norms of reciprocity, trust, and associations that bridge social divisions are a central part of social cohesion that fosters community capacity ((Kawachi and Berkman, 2000)). In the occurrence of extreme events, affected groups interact with one another in an attempt to develop a set of norms appropriate to the situation, otherwise known as emergent norm theory of collective behavior ((NRC (National Research Council), 2006)). This is true of those first affected at the local level whose norms and related social capital affect capacity for response ((Dolan and Walker, 2004)).

Social capital is a multifaceted concept that captures a variety of social engagement within the community that bonds people and generates a positive collective value. It is suggested as an important element in the face of climate extremes because community social resources such as networks, social obligations, trust, and shared expectations create social capital to prevent, prepare, and cope with disasters ((Dynes, 2006)). In climate change adaptation, scholars and policymakers increasingly promote social capital as a long-term adaptation strategy ((Adger, 2003; Pelling and High, 2005)). Social capital, however, can be driven by internal social networks and is oftentimes a function of the extent of community know-how and networks, which could become self-referential and insular ((Dale and Newman, 2010; Portes and Landolt, 1996)). This results in a closed society that lacks of innovation and diversity essential for climate change adaptation. Disaster itself is overwhelming, and can lead to the erosion of social capital and the demise of the community ((Ritchie and Gill, 2007)). This invites external engagement beyond local-level treatment of the disaster and extreme events ((Brondizio *et al*., 2009)(Cheong, 2010)). The inflow of external aids, expertise, and the emergence of new groups to cope with disaster are indicative of the necessity of bridging and linking social capital beyond local boundaries.

Social capital is embedded in social networks ((Lin, 2001)), or the social structure composed of individuals and organizations through multiple types of dependency, such as kinship, financial exchange, or prestige ((Wellman and Berkowitz, 1988)). Social networks provide a diversity of functions, such as facilitate sharing of expertise and resources across stakeholders ((Crabbé, 2006)). Networks can function to promote messages within communities through preventive advocacy, or the engagement of advocates in promoting preventive behavior ((Weibel, 1988)(Weibel, 1988)). Information about health risks has often been effectively distributed through a social network structure using opinion leaders as a guide ((Valente and Davis, 1999; Valente *et al*., 2003)), and has promising application for changing behavior regarding climate adaptation ((Maibach *et al*., 2008)). It is important to note that more potential has been shown in influencing behavior through community-level interventions than through individual-level directives at the population level ((Kawachi and Berkman, 2000)). Therefore, communities with stronger social networks are more likely to be prepared for extreme climate impacts because of access to information and social support ((Buckland and Rahman, 1999)).

At the same time, it is important to note that social networks can also function to discourage effective adaptation to extreme events. External support, such as financial resources, may actually create inequalities amongst community members resulting in contention and weakened social networks ((Ford *et al.*, 2006)). The utilization of social networks can also be prevented by the status of particular social groups, such as illegal and legal settlers or immigrants ((Wisner *et al.*, 2004)). Other social and environmental contextual factors must be considered when conceptualizing the role of social networks in managing extreme events. For example, strong social networks have facilitated adaptability in Inuit communities, but are being undermined by the dissolution of traditional ways of life ((Ford *et al.*, 2006)).

5.3.5.5. Integrating Local Knowledge

Local and traditional knowledge is increasingly valued as important information to include when preparing for disasters ((McAdoo *et al.*, 2009; Shaw *et al.*, 2009)). It is embedded in local culture and social interactions and transmitted orally over generations ((Berkes, 2008)). Place-based memory of vulnerable areas, know-how for responding to recurrent extreme events, and detection of abnormal environmental conditions manifest the power of local knowledge. Because local knowledge is often tacit and invisible to outsiders, it is used to reveal and enhance community participation in disaster management ((Battista and Baas, 2004)). Turner *et al.* ((Turner and Clifton, 2009)) state that participation of indigenous peoples provides local knowledge, and other alternative adaptation approaches. Local knowledge is also an important anchor for communities in relating to external knowledge such as scientific knowledge and national policies. In many places where local knowledge is used, communities set up trusted intermediaries to transfer and communicate external knowledge such as a technology-based early warning system and incorporate into the local knowledge system ((Bamdad, 2005; Kristjanson *et al.*, 2009)).

Within a climate change context, indigenous people, who are long-term residents who have often conserved their resources *in situ*, provide important information about changing environmental conditions ((Salick and Ross, 2009)(Turner and Clifton, 2009)) as well as actively adapting to the changes ((Macchi *et al.*, 2008; Salick and Byg, 2007)). Research is emerging in helping to document changes that indigenous people (people living with local and traditional cultures)((Salick and Ross, 2009)) are experiencing ((Ensor and Berger, 2009)(Ensor and Berger, 2009)). Although this evidence might be similar to scientific observations from external researchers, the fact that local communities are observing it is initiating discussions existing and potential adaptation to these changes from within the community ((Byg and Salick, 2009)). In six villages in eastern Tibet, near Mt. Khawa Karpo, documentation of changes experienced by local indigenous groups were consistent across areas, such as warmer temperatures, less snow, and glacial retreat, whereas other observations were more varied, including those for river levels and landslide incidences ((Byg and Salick, 2009)). In Gitga'at (Coast Tsimshian) Nation of Hartley Bay, British Columbia, indigenous people are noticing the decline of some species but also new appearances of others, anomalies in weather patterns and declining health of forests and grasslands that have affected their ability to harvest food ((Turner and Clifton, 2009)).

One of the challenges of biodiversity changes related to the climate is that many indigenous people depend on the variety of wild plants, crops and their environments particularly in times of disaster ((Turner and Clifton, 2009)). Changes in biodiversity are threatening historical coping strategies. There are numerous other challenges that indigenous people have to face in coping with climate change. In dryland areas such as in Namibia and Botswana one of the indigenous strategies best adapted to frequent droughts is livestock herding, including nomadic pastoralism ((Ericksen *et al.*, 2008)). Decreased access to water sources through fencing and privitization has inhibited this robust strategy. Also in Botswana, it has been suggested that government policies have weakened traditional institutions and practices, as they have not adequately engaged with local community institutions and therefore the mechanisms for redistributing resources have not been strengthened sufficiently ((Dube and Sekhwela, 2008)).

5.3.5.6. Local Government and Non-Government Initiatives and Practices

Governance structures are pivotal as they help shape efficiency, effectiveness, equity, and legitimacy of responses ((Adger *et al.*, 2003)). Current climate change management practices have tended to be centralized at the national level. This may be, in part, due to the ways in which many climate extremes affect environmental systems that cross political boundaries resulting in discordance if solely locally managed ((Cash and Moser, 2000)). Actions generated within and managed by communities, however, can be most effective since they are context-specific and tailored to local environments. If multiple levels of planning are to be implemented, mechanisms for facilitation and guidance on the local level are needed in order that procedural justice is guaranteed during the implementation of national policies at the local scale ((Thomas and Twyman, 2005)). In this light, local governments play an important role as they are responsible for providing infrastructure, preparing and responding to disasters, developing and enforcing planning, and connecting national government programs with local communities ((Huq *et al.*, 2007; UNISDR, 2009)). The quality and provision of these services have an impact on disaster and climate risk ((Tanner *et al.*, 2009)). Effective localized planning, for example, can minimize both the causes and consequences of climate change ((Bulkeley, 2006)). (Tanner *et al.*, 2009)

Though local government–led climate adaptation policies and initiatives are less pronounced than climate change mitigation measures, a growing number of cities are developing adaptation plans, though few have implemented their strategies ((Heinrichs, 2009); (Birkmann *et al.*, in press; Birkmann *et al.*, in press)). The Greater London Authority ((Greater London Authority, 2010)), for example, has prepared a Public Consultation Draft of their climate change adaptation strategy for London. The focus of this is on the changing risk of flood, drought and heat waves through the century and actions for managing them. Some of the actions include improvement in managing surface water flood risk, an urban greening program to buffer the impacts from floods and hot weather, and retro-fitting homes to improve the water and energy efficiency.

An assessment of the current state of progress on adaptation in eight cities (Bogotá, Cape Town, Delhi, Perl River Delta, Pune, Santiago, Sao Paulo and Singapore) suggests that adaptation tend to support existing disaster management strategies ((Heinrichs, 2009)). Another study comparing adaptation plans in nine cities including Boston, Cape Town, Halifax, Ho Chi Minh City, London, New York, Rotterdam, Singapore, and Toronto suggests that these cities' adaptation plans focus mostly on risk reduction and the protection of citizens and infrastructure, with Rotterdam seeing adaptation as opportunity for transformation ((Birkmann *et al.*, in press)). Most of these strategies have been led by Mayor's offices or environment departments. These nine cities have focused more on expected biophysical impacts than on socio-economic impacts and have not had a strong focus on vulnerability and the associated susceptibility or coping capacity. Although they aim to be integrated, they tend to have sectoral responses. Unfortunately with many of these cases, there is a good understanding of the impacts associated but the implementation of policy and outcomes on the ground are harder to see ((Bulkeley, 2006); (Burch and Robinson, 2007)).

In these adaptation strategies, the size of the local government is important, and it varies depending on the population and location. Primate and large cities exert more independence, whereas smaller municipalities depend more on higher levels of the government units, and often form associations to pool their resources ((Lundqvist, 2008)). In the latter case, state mandated programs and state-generated grants are the main incentives to formulate mitigation policies ((Aall, C., K. Groven,G.Lindseth, 2007)) and can be applicable to adaptation policies. Lack of resources and capabilities lead to outsourcing of local adaptation plans, and can generate insensitive and unrefined local solutions and technological fixes ((Crabbé, 2006)). To address this problem, participatory approaches are used to generate integrated assessments at the local level of vulnerabilities and formulate adaptation action plans.

The history and process of decentralization are also significant in the capacity of the local government to formulate and implement adaptation policies. Aligning local climate adaptation policies with the state/provincial and national/federal units is a significant challenge for local governments ((Van Aalst *et al.*, 2008)). Instead of the scaling up from localized assessments to national-level plans, communities often adopt mainstream climate change into the existing national and local policies ((Roberts, 2008)).

Although government actors play a key role, it is evident that non-government actors are crucial as well. While international agencies and NGOs play a norm-setting agenda at provincial, state, and national levels, community-based organizations (CBOs) often have greater capacity to mobilize at the local scale ((Milbert, 2006)). NGO and CBO networks play a critical role in capturing the realities of local livelihoods, facilitating sharing information, and identifying the role of local institutions that lead to strengthened local capacity ((Bull-Kamanga *et al.*, 2003)). Strong city-wide initiatives are often based on strategic alliances and local community organizations are essential to operationalizing city planning ((Hasan, 2007)(Hasan, 2007)).

Many non-government actors charged with managing climate risks use community risk assessment tools to engage communities in risk reduction efforts and influence planning at local and sub-national levels ((van Aalst, 2006)). NGO engagement in risk management activities ranges from demonstration projects, training and awareness-raising, legal assistance, alliance building, small-scale infrastructure, socio-economic projects, and mainstreaming and advocacy work ((Luna, 2001) (Shaw, 2006)). Bridging citizen-government gaps is a recognised role of civil society organisations and NGOs often act as social catalysts or social capital, an essential for risk management in cities ((Wisner, 2003)). Conversely, the potential benefits of social capital are not always maximised due to mistrust, poor communications or dysfunctionalities either within municipalities or non-government agencies. This has major implications for risk reduction ((Wisner, 2003)) and participation of the most vulnerable in non-government initiatives at municipal or sub-national level is not guaranteed ((Tanner *et al.*, 2009)).

5.4. Challenges and Opportunities

There are two key principles in disaster risk reduction that are applicable to climate change adaptation: 1) mainstreaming disaster prevention and mitigation into normal policies addressing social welfare, quality of life, infrastructure, and livelihoods; and 2) incorporating an all-hazards approach into planning and action. Disaster reduction is not only about reducing risks and exposure, but also includes systematic efforts to analyze and manage the causal factors of disasters by lessening societal vulnerability, improving land and environmental stewardship, improving preparedness, and enhancing societal resilience ((Bohle and Warner, 2008; Wisner, 2003)). Each presents challenges and opportunities for adaptation to climate extremes.

5.4.1. Differences in Coping and Risk Management

There are significant differences among communities and population groups in the ability to prepare for, respond to, recover from and adapt to disasters and climate extremes. For nearly sixty years, social science researchers have examined those factors that influence coping responses by households and communities through post-disaster field investigations as well as pre-disaster assessments ((Mileti, 1999; NRC (National Research Council), 2006)). Among the most significant individual characteristics are gender, age, wealth, ethnicity, livelihoods, entitlements, and health in the context of urban/rural divide. However, it is not only these characteristics operating individually, but also their synergistic effects that give rise to variability in coping and managing risks.

5.4.1.1. Gender

The literature suggests that at the local level gender makes a difference in vulnerability (Chapter 2), but it is also important in coping and risk management. In disasters, women tend to have different coping strategies and constraints on actions than men ((Peacock *et al.*, 2000)(Morrow and Enarson, 1996)(Fothergill, 1996)). These are due to the social position (class), marital status, education, wealth, and their caregiver roles. At the local level for example, women's lack of mobility and social isolation found in many places across the globe tend to augment risk, exposure, and vulnerability ((League of Red Cross and Red Crescent Societies, 1991; League of Red Cross and Red Crescent Societies, 1991; Mutton and Haque, 2004; Mutton and Haque, 2004; Schroeder, 1987)). Relief and recovery operations are often insensitive to gender issues, and so the provision of such supplies and services also influences the differential capacities to cope ((Enarson, 2000)(Fulu, 2007); (Ariyabandu, 2006; Wachtendorf *et al.*, 2006)).

5.4.1.2. Age

Age acts as an important factor in coping with disaster risk ((Cherry, 2009)). In North America, for example, retired people often choose to live in hazardous locations such as Florida or Baja California because of warmer weather and lifestyles, which in turn increases their potential exposure to climate-sensitive hazards. At the same time, older people are more prone to ill health, isolation, disabilities, and immobility ((Dershem and Gzirishvili, 1999; Ngo, 2001)), which negatively influence their coping capacities in response to extreme events (see Heat Case Study in Chapter 9). Often because of lack of declining hearing, mental capabilities, or mobility, older persons are less likely to receive warning messages, take protective actions, and are more reluctant to evacuate ((Hewitt, 1997; O'Brien and Mileti, 1992)). However, older people have more experience and wisdom with accumulated know-how on specific disasters/extreme events as well as the enhanced ability to transfer their coping strategies arising from life experiences.

At the other end of the age spectrum are children ((Peek, 2008)). Research has shown significant diminishment of coping skills (and increases in post-traumatic stress disorder and other psychosocial effects) among younger children following Hurricane Katrina ((Weems and Overstreet, 2008) (Barrett *et al*., 2008). In addition to physical impacts and safety ((Lauten and Lietz, 2008; Weissbecker, I., Sephton, S.E. *et al*., 2008)(Lauten and Lietz, 2008; Weissbecker, I., Sephton, S.E. *et al*., 2008)), research also suggests that emotional distress caused by fear of separation from the family, and increased workloads following disasters affects coping responses of children ((Babugura, 2008; Ensor, 2008)). However, the research also suggests that children are quite resilient and can adapt to environmental changes thereby enhancing the adaptive capacity of households and communities ((Pfefferbaum *et al*., 2008; Williams *et al*., 2008) (Bartlett, 2008; Manyena *et al*., 2008; Mitchell *et al*., 2008; Ronan *et al*., 2008)).

5.4.1.3. Wealth

The level of wealth at the local level affects the ability of a person/community to prepare for, respond to, and rebound from disaster events ((Masozera *et al*., 2007)). Wealthier communities have a greater potential for large monetary losses, but at the same time, they have the resources (insurance, income, political cache) to cope with the impacts and recover from extreme events. In Asia, for example, wealth shifted construction practices from wood to masonry which made many of the cities more vulnerable and less able to cope with disaster risk ((Bankoff, 2007)). Poorer communities and populations often live in cheaper hazard-prone locations, and face challenges not only in responding to the event, but also recovering from it. Poverty also enhances disaster risk ((Carter *et al*., 2007)). In some instances, it is neither the poor nor the rich that face recovery challenges, but rather communities that are in-between such as those not wealthy enough to cope with the disaster risk on their own, but not poor enough to receive full federal or international assistance. The recovery of New Orleans after Hurricane Katrina provides one example ((Finch *et al*., 2010)).

5.4.1.4. Intersectionality of Gender, Class, Age, and Ethnicity

The key characteristics that seem to influence social vulnerability were noted in Chapter 2 and elsewhere (Cutter *et al*., 2003). However, the individual characteristics of a person/family/community do not, indeed cannot, determine vulnerability to hazard events alone or how the family or community will cope with disaster risk. Rather, it is the interaction between all of these factors across space and through time results in a complicated system of stratification of wealth, power and status ((Heinz Center, 2002)). One of the best examples of this is the human experience with Hurricane Katrina (see Box 5-7): the intersection of race, class, age, and gender influenced differential decision making and perception of hazards; an uneven distribution of vulnerability and exposure resulting in disproportionate disaster losses; diverse types of hazard preparedness and disaster mitigation; and variable access to post-event aid, recovery and reconstruction(Elliott and Pais, 2006; Elliott and Pais, 2006; Hartman and Squires, 2006; Tierney, 2006)).

_____ START BOX 5-7 HERE _____

Box 5-7. Case Study – Hurricane Katrina Recovery and Reconstruction

Evacuation can protect people from injury and death, but extended evacuations (or temporary displacements lasting weeks to months) can have negative effects. Prolonged periods of evacuation can result in a number of physical and mental health problems ({{(Curtis *et al.*, 2007; Mills *et al.*, 2007)). Furthermore, separation from family and community members and not knowing when a return home will be possible also adds to stress among evacuees ((Curtis *et al.*, 2007)Curtis et al., 2007). DeSalvo *et al.* ((DeSalvo *et al.*, 2007)) found that long periods of displacement were among the key causes of post traumatic stress disorder in a study of New Orleans workers. These temporary displacements can also lead to permanent outmigration by specific social groups as shown by the depopulation of New Orleans five years after Hurricane Katrina ((Myers *et al.*, 2008)).

_____ END BOX 5-7 HERE _____

5.4.1.5. Livelihoods

Livelihood is the generic term for all the capabilities, assets, and activities required for a means of living. Livelihood influences how families and communities cope with and recover from stresses and shocks ((Carney, 1998)). For poor communities living on fragile and degraded lands deteriorating environmental conditions undermine their livelihoods and capacity to cope with disasters. For example in areas where extreme climates are expected to increase in duration and frequency, certain community-based development activities, in particular, those that are characterized as sustainable livelihoods (SL) activities serve to build adaptive capacity and resilience to shocks ((Osman-Elasha, 2006b)).

Protecting and enhancing the natural services that buffer communities from climate impacts and provide them with a range of assets for coping with shocks will not only address immediate development priorities, but could improve local capacities to adapt to climate change ((Osman-Elasha, 2008; Spanger-Siegfried *et al.*, 2005)). Sustainable strategies for disaster reduction help improve livelihoods (UNISDR, 2004)); while social capital, such as community networks support adaptation and disaster risk reduction by reducing the need for emergency relief in times of drought and/or crop failure ((Devereux and Coll-Black, 2007)) (see 5.2.5). A research study in South Asia suggests that adaptive capacity and livelihood resilience depend on social capital at the household level (i.e. education and other factors that enable individuals to function within a wider economy), the presence or absence of local enabling institutions (local cooperatives, banks, self-help groups), and the larger physical and social infrastructure that enables goods, information, services and people to flow. Interventions to catalyze effective adaptation are important at all these multiple levels ((Moench and and Dixit, 2004)).

5.4.1.6. Entitlements

Extreme climate events generally lead to entitlement decline in terms of the rights and opportunities that local people have to access and command the livelihood resources that enable them to deal with and adapt to climate stress. Entitlement decline can affect environmental entitlements ((Leach *et al.*, 1999)), food entitlements ((Sen, 1981)) and, more generally, all the material, social, political and cultural resources that are the basic building blocks of any coping and adaptation options towards disaster risk and climate stress.

The buffering capacities of local people's livelihoods and their institutions are critical for their adaptation to extreme climate stress. More specifically, adaptive capacities rest on the ability of communities to generate potentials for self-organization, for social learning and innovations ((Adger *et al.*, 2006)), with a focus on social actors, their practices and their agency that allow for resilient transformations ((Bohle, H.-G., B. Etzold,M.Keck, 2009)). Community institutions regulate the access to adaptation resources. Institutions, as purveyors of the rules of the game ((North, 1990)), mediate the socially differential command over livelihood assets, thus determining protection or loss of entitlements. These rules are constantly made and remade through local people's social practices, but they are also contested and struggled over ((Bohle, H.-G., B. Etzold,M.Keck, 2009)). Entitlement protection thus requires adaptive types of institutions and patterns of behaviour ((Bohle, H.-G., B. Etzold,M.Keck, 2009)), with a focus on local people's agency within specific configurations of power relations. The challenge is therefore, to empower the most vulnerable to pursue livelihood options that strengthen their entitlements and protect what they themselves consider the social sources of adaptation and resilience in the face of extreme climate stress.

5.4.1.7. Health and Disability

Climate change contributes to 160,000 annual deaths globally due to vector borne diseases, food insecurity, heat waves and other problems ((Campbell-Lendrum *et al.*, 2003)). The extreme impacts of climate change (Chapters 3 and 4) are likely to directly or indirectly affect the health of many populations. Mortality rates may increase, and morbidity of a diversity of illnesses can increase. Extreme temperature rise leads to heatstroke, while cardiopulmonary problems and respiratory illness are linked to shifts in air pollution concentrations such as ozone ((Bernard *et al.*, 2001)). Extreme heat events differentially affect populations based on their race, gender, age ((Díaz *et al.*, 2002)), and medical and socioeconomic status (McGeehin and Mirabelli 2001), consequently raising concerns about health inequalities (see Chapter 9 case study). Vector-borne illnesses are projected to increase in geographic reach and severity as temperatures increase ((McMichael *et al.*, 2006)). As seasons lengthen, mosquitoes and other vectors begin to inhabit areas previously free from such vectors of transmission. A range of vector-borne illnesses has been linked to climate, including malaria, dengue, Hantavirus, Bluetongue, Ross River Virus, and cholera (Patz et al. 1996).

The disaster literature generally discusses public health and disability as important in the response (post event) phase of the event cycle ((Shoaf and Rottmann, 2000)). Literature in the public health field also suggests that pre-existing health conditions can exacerbate the impact of disaster events since these populations are more susceptible to additional injuries from disaster impacts ((Brauer, 1999); (Brown, 1999; Parati *et al.*, 2001)). Pre-event health conditions/disabilities can also lead to subsequent communicable diseases and illnesses in the short term, to lasting chronic illnesses, and to longer term mental health conditions ((Shoaf and Rottmann, 2000)(Bourque *et al.*, 2006; Few and Matthies, 2006)).

There are few consistent databases for monitoring mortality from natural hazards ((Borden and Cutter, 2008; Thacker *et al.*, 2008)). However, two recent all-hazards studies for the U.S. found from 1970-2004, climate-sensitive hazards (severe weather in the summer and winter, and heat) accounted for the majority of recorded fatalities from natural hazards. Geographically, fatalities were greatest in the coastal counties bordering the Gulf of Mexico and South Atlantic (the U.S. hurricane coast), in rural counties, and in the American South ((Borden and Cutter, 2008)).

5.4.1.8. Urban/Rural

Settlement patterns are another factor that influences disaster risk management and coping with extremes. In many countries, rural livelihoods and poverty are the drivers of disaster risk and this will intensify under climate extremes. Poverty, resource scarcity, and access to resources constrains disaster risk management and when coupled with climate variability, conflict, and health issues further compounds the coping capacity of rural places ((UNISDR, 2009)). At the other extreme are the concentrated settlements of cities where the disaster risks are magnified because of population densities, poor living conditions including overcrowded and substandard housing, lack of sanitation and clean water, and health impairments from pollution among others issues ((Bull-Kamanga *et al.*, 2003; De Sherbinin *et al.*, 2007)). Strengthening local capacity in terms of housing, infrastructure, and disaster preparedness is one mechanism shown to improve urban resilience, and the adaptive capacity of cities to climate-sensitive hazards ((Pelling, 2003)).

Given the rapid rate of growth in the largest of the world's cities, called megacities and mega-regions, the disaster risks will increase in the next decade placing more people in harm's way with untold billions of dollars in infrastructure located in highly exposed areas ((Wenzel *et al.*, 2007); (Kraas *et al.*, 2005);(Munich Re Group, 2004)). The complex and dynamic interaction between social, economic, political, and environmental processes insures that when a disaster strikes one of these megacities or mega-regions, there will be catastrophic losses of lives, property, and economic wealth resulting in major humanitarian crises ((Mitchell, 1999)).

For many regions, the ability to limit exposure has already been achieved through building codes, land management, and structural mitigation, yet losses keep increasing. For disaster reduction to become more effective, megacities will need to address their societal vulnerability and the driving forces that produce it (rural to urban migration, livelihood pattern changes, wealth inequities). Many megacities have reached their tipping points, and are seriously compromised in their ability to prepare for and respond to present disasters, let alone adapt to future ones influenced by climate change ((Heinrichs, 2009; World Bank, 2009);(Fuchs, 2009)).

5.4.2. Costs of Managing Disaster Risk and Risk from Climate Extremes

Large-scale disasters can cause considerable economic damage, on the order of magnitude of one percentage point of total wealth or several percentage points of GDP, which could threaten economic growth ((ADB, 2003); (Stern, 2007; Stern, 2007)(Cummins and Mahul, 2008)). Studies demonstrated that disaster prevention and mitigation can pay high dividends. For example Mechler (Mechler, 2005) found that for every Euro invested broadly in risk management, 2 to 4 Euros were returned in terms of avoided or reduced disaster impacts on life, property, the economy and the environment). In the United States, the Multihazard Mitigation Council found that for every dollar invested in pre-impact mitigation activities, four dollars were saved in potential losses ((Multihazard Mitigation Council, 2005)). There is a growing recognition of the potential role of social protection as a response to the multiple risks and stressors associated with disaster management and climate extremes, however little is known about local practices and cost-savings.

5.4.2.1. Costs of Impacts, Costs of Post-Event Responses

It is extremely difficult to assess the total cost of a large scale event, such as Hurricane Katrina, especially at the local scale. Direct and indirect losses are two ways to account for the costs of impact (see Chapter 4). Direct losses can be separated into direct market losses and direct non-market losses (intangible losses). They include health impacts, loss of lives, natural asset damages and ecosystem losses, and damages to historical and cultural assets. Indirect losses [also labelled higher-order losses ((Rose, 2004) or hidden costs ((Heinz Center, 1999))] include all losses that are not provoked by the disaster itself, but by its consequences. Measuring indirect losses is important as it evaluates the overall economic impact of the disaster on society. The assessment of indirect losses is difficult at the local scale because of the limited availability of economic data at this level. In addition, the relationship between the affected area and the world beyond can complicate the assessment. For example, local losses can be compensated from various inflows of goods, workers, and capital from outside the area to assist with reconstruction, along with governmental or foreign aid ((Eisensee and Stromberg, 2007)). At the same time, local disasters can provide ripple effects and influence world markets, such as Hurricane Katrina’s impact on the world oil market, when most of the Gulf of Mexico oil rigs were shut down for weeks. Trade-offs in business loss and gain at different spatial scales need to be considered in accounting for indirect losses at the local level.

Despite the difficulties noted above, many local studies exist. For example, Strobl ((Strobl, 2008)) provided an econometric analysis of the impact of the hurricane landfall on county-level economic growth in the U.S. This analysis showed that a county struck by at least one hurricane over a year saw its economic growth reduced on average by 0.79%, and increased by 0.22% the following year. The economic impacts of the 1993 Mississippi flooding in the U.S. showed significant spatial variability within the affected regions. In particular, states with a strong dependence on the agricultural sector had a disproportionate loss of wealth compared to states that had a more diversified economy ((Hewings and Mahidhara, 1996; Hewings and Mahidhara, 1996)}}). Noy and Vu ((Noy and Vu, 2009)) investigated the impact of disasters on economic growth in Vietnam at the provincial level, and found that fatal disasters decreased economic production while costly disasters increased short-term growth. Studies also found that regional indirect losses increase nonlinearly with direct losses ((Hallegatte, 2008)), and can be compensated by importing reconstruction means (workers, equipment, finance) from outside the affected regions.

5.4.2.2. Adaptation and Risk Management-Present and Future

Adaptation cost estimates are based on various assumptions about the baseline scenario and the optimality of adaptation measures. The difference between these assumptions makes it impossible to compare or aggregate results. Yohe *et al.* ((Yohe, G., J. Neumann, P. Marshall,H.Ameden, 1996; Yohe, G., J. Neumann,H.Ameden, 1995; Yohe *et al.*, 2011)) and West *et al.* ((West, J., Small, MJ, and Dowlatabadi, H., 2001)), for example, assess the economic cost of the sea-level rise in the United States for two baselines. The first baseline (perfect foresight) presumed that efficient coastal real estate markets would internalize impending inundation from rising seas and depreciate the economic value of any structure that would not be protected to zero, just as the waters arrived. The second baseline (no-foresight) assumes that property owners would maintain their properties as long as possible (for various reasons including imperfect anticipation and moral hazard linked to likely public support). Estimates of the economic cost of rising seas including the cost of adaptation were significantly higher in the no-foresight baseline.

In another study involving the water sector, Venkatesh and Hobbs ((Venkatesh, 1999)) investigated the role of uncertainty on future climate change in investment decision-making, and demonstrated the value of deferring decision to wait for additional information to avoid the consequences of inadequate adaptation. In the agriculture sector, estimates have been done using various assumptions on adaptation behavior ((Schneider, S.H., K. Kuntz-Duriseti,C.Azar, 2000)), from the farmers who do not react to observed changes in climate conditions (especially in studies that use crop yield sensibility to weather variability((Deschenes, 2007; Lobell, D.B., M. B. Burke, C. Tebaldi, M. D. Mastrandrea, W. P. Falcon,R.L.Naylor, 2008; Schlenker, 2010)) to the introduction of selected adaptation measures within crop yield models ((IFRI, 2009; Rosenzweig, 1994)) to the assumption of perfect adaptation with Ricardian approaches ((Kurukulasuriya, 2008a; Kurukulasuriya, 2008b; Mendelsohn, 1999; Seo, 2008)). Realistic assessments fall between these extremes, and a realistic representation of future adaptation pattern depend on the in-due-time detection of the climate change signal ((Hallegatte, 2009; Schneider, S.H., K. Kuntz-Duriseti,C.Azar, 2000)); the inertia in adoption of new technologies ((Reilly, 2000)); the existence of price signals ((Fankhauser *et al.*, 1999)); and non-rational behavior.

Adaptation choices to climate extremes at the city scale often employed simplified catastrophe risk assessments. Jacob *et al.* ((Jacob, K., V. Gornitz, C. Rosenzweig, L. McFadden, R. Nicholls,E.Penning-Rowsell (eds.), 2007)) investigated the vulnerability of the New York City metropolitan area to coastal hazards and sea level rise and found that without any adaptation a 1-meter sea level rise would increase mean annual losses due to storm surges by a factor of three. A different study of New York City by Rosenzweig and Solecki ((Rosenzweig, 2001)) used historical analogues to derive annualised losses for different storm frequencies. They calculated projected damages of approximately 0.1% of Gross Regional Product, annualised, and a probable maximum loss of 10-25% of GRP for one event. Hallegatte *et al.* ((Hallegatte, S., N. Ranger, O. Mestre, P. Dumas, J. Corfee-Morlot, C. Herweijer,R.Muir Wood, 2010)) and Ranger *et al.* ((Ranger, N., S. Hallegatte, S. Bhattacharya, M. Bachu, S. Priya, K. Dhore, F. Rafique, P. Mathur, N. Naville, F. Henriet, C. Herweijer, S. Pohit,J.Corfee-Morlot, 2010)) coupled direct economic impact analyses with an economic input-output (IO) model to assess losses for Copenhagen and Mumbai, respectively. The output is an assessment of the direct and indirect economic impacts of storm surge under climate change including production, job losses, reconstruction time, and the benefits of investment in upgraded coastal defences. In Copenhagen, mean annual losses are currently negligible, but would soar even with only a limited rise in sea level in the absence of upgraded protection; protection that is relatively inexpensive in financial terms. Ranger *et al.* ((Ranger, N., S. Hallegatte, S. Bhattacharya, M. Bachu, S. Priya, K. Dhore, F. Rafique, P. Mathur, N. Naville, F. Henriet, C. Herweijer, S. Pohit,J.Corfee-Morlot, 2010)) found that losses from the 1-in-100 year rainfall flood in Mumbai could be multiplied by a factor of 3 under a pessimistic climate change scenario. However adaptation could significantly reduce those future losses by as much as 70%.

Studies on the costs of local disaster risk management are scarce, fragmented, and conducted mostly in rural areas. One study estimated the cost/benefit ratio of disaster management and preparedness programs in villages of Bihar and Andra Pradesh, India to be 3.76 and 13.38, respectively ((Venton and Venton, 2004)). Research undertaken by the Institute for Social and Environmental Transition (ISET) on a number of cases in India, Nepal and Pakistan also consistently demonstrated positive benefit to cost ratios and notes that return rates are particularly robust for lower-cost, local level interventions (including such actions as raising house plinths and fodder storage units, community based early warning, establishing community grain or seed banks, and local maintenance of key drainage points) when compared to embankment infrastructure strategies that require capital investment ((Moench, M.,and the Risk to Resilience Study Team, 2008)). The studies demonstrated a sharp difference in the effectiveness of the two approaches, concluding that the embankments historically have not had an economically satisfactory performance. In contrast, the benefit/cost ratio for the local level strategies indicated economic efficiency over time and for all climate change scenarios ((Dixit, A., Pokhrel, A, and Marcus Moench, M, 2008)).

5.4.2.3. Consistency and Reliability of Cost and Loss Estimations at Local Level

There are inconsistencies in present disaster risk loss data at all levels—local, national, global—which ultimately influences the accuracy of such estimates (Downton and Pielke Jr., 2005; Guha-Sapir and Below, 2002; Pielke Jr. *et al.*, 2008). The reliability of disaster economic loss estimates is especially problematic at the local level due to: 1) the spatial coverage and resolution of databases that are global in coverage, but only at the national level with no consistent sub-national data; 2) thresholds for inclusion where only large economically-significant disasters are included, thus biasing the data toward singular events with large losses, rather than multiple, smaller events with fewer losses; and 3) what gets counted varies between databases (e.g. insured vs. uninsured losses; direct vs. indirect)((Gall *et al.*, 2009)).

Similarly, there is a large uncertainty on impact and adaptation costs, again for multiple reasons. First, there is a large uncertainty in future emissions of greenhouse gases, which translates into a large uncertainty in the amplitude of future global climate change ((Solomon *et al.*, 2007)). Second, there are uncertainties in the magnitude and pattern of local climate change, and of local climate variability and extremes (see Chapter 3). Third, the assessment of climate change impacts at the local scale is difficult, especially the lack of consensus on the discount rate ((Heal, 1997; Tol, 2003); (Nordhaus, 2007; Stern, 2007; Weitzman, 2007)) and on the evaluation of non-market costs, especially the value of biodiversity or cultural heritage ((Pearce, 1994)). Finally, the possibility of low-probability high-consequence climate change is not fully included in most analysis ((Lonsdale *et al.*, 2008; Nicholls *et al.*, 2008; Stern, 2007; Weitzman, 2009)).

5.4.3. Limits to Adaptation

If extreme events happen more frequently and/or with greater intensity/magnitude some locations may be uninhabitable for lengthy and repeated periods rendering sustainable development impossible. In such a situation, not all communities will be able to adapt without considerable disruption and costs (economic, social, cultural and psychological) and in some cases forced migration may be the only alternative ((Brown, 2008)). Changes in mean conditions may cause the effects of extreme events to be magnified. For example, sea level rise may cause storm surges to reach greater heights and move increased distances inland from the shore. On atolls, such changes may lead to complete inundation during storm events, occurrences which already occur during major tropical cyclones. Such inundation renders the ghyben-herzberg freshwater lens, critical for water supply and agriculture, saline and unusable for extended periods of time ((Anderson, 2002; Burns, 2003)). Water supplies on atolls may be increasingly tenuous if climate change causes increased incidence or duration of drought events ((Barnett and Adger, 2003)). These conditions may be exacerbated by coastal erosion ((World Bank, 2000)), with many atolls becoming increasingly uninhabitable. The only adaptation option may be the migration of whole communities and in the cases of countries comprising only atolls such relocation would need to be international in scale ((Campbell, 2010b)).

Densely populated regions in developing countries suffer the brunt of natural disasters ((UNISDR, 2004)). More than half of the global population now lives in urban areas with an increasing population exposed to multiple risk factors ((UNFPA, 2009)). Risk is increasing in urban agglomerations of different size due to unplanned urbanization and accelerated migration from rural areas or smaller cities ((UN-HABITAT, 2007)). The 2009 Global Assessment Report on Disaster Risk Reduction ((UNISDR, 2009)) lists unplanned urbanization and poor urban governance as two main underlying factors accelerating disaster risk. It highlighted that the increase in global urban growth of informal settlements in hazard prone areas reached 900 millions in informal settlements, increasing by 25 million per year. Urban hazards exacerbate disaster risk by the lack of investment in infrastructure as well as poor environmental management, thus limiting the adaptive capacity of these areas.

Local actions on adaptation face many types of constraints depending on the type of hazard and degree of exposure as well as the availability and accessibility to information and knowledge. For example, communities living in areas prone to climate extremes such as frequent drought have developed certain coping/survival responses that assisted them to survive harsh conditions. Over time, these coping responses proved inadequate due to the magnitude of the problem ((Ziervogel *et al*., 2006)). The information gap is particularly evident in many developing countries with limited capacity to collect, analyze and use demographic and mortality data on mortality and demographic trends, as well as evolving environmental conditions ((IDRC, 2002; National Research Council, 2007); (Carraro *et al*., 2003)). Based on Fischer *et al.* ((Fischer *et al*., 2001)) closing the information gap is critical to reduce climate change related threats to rural livelihoods and food security in Africa. Moreover, the lack of access to information by local people has reduced improvements in knowledge, understanding and skills, needed elements to help communities undertake improved measures to protect themselves against disasters and climate change impacts ((Agrawal *et al*., 2008)). Improving community access to information and control over resources will have a great bearing on their capacity to prepare, mitigate, manage, and respond and recover from any future disaster.

Lack of capacities and skills, particularly by women also has been identified as a limiting factor for effective local adaptation actions ((Osman-Elasha *et al*., 2006)). Reducing community’s vulnerabilities particularly women’s through capacity-building and instilling new skills and knowledge proved an effective approach for improving the local adaptive capacity. A successful initiative in Mali involves empowering women and giving them the skills to diversify their livelihoods, thus linking environmental management, disaster risk reduction, and the position of women as key resource managers (UN, 2008).

In developed countries, household decisions regarding disaster risk reduction, and by extension, adaptation, are often guided by factors other than cost. For example, Kunreuther and Michel-Kerjan ((Kunreuther *et al*., 2009)) found that most individuals underestimate the risk and do not make cost-benefit trade-offs in their decisions to purchase hazard insurance and/or have adequate coverage. They also found empirical evidence to suggest that the hazard insurance purchase decision was driven not only by the need to protect assets, but also to reduce anxiety, satisfy mortgage requirements, and social norms (p. 120). For other types of mitigation activities, households do not voluntarily invest in cost-effective mitigation because of underestimating the risk, taking a short-term rather than long-term view, and not learning from previous experience (p. 247). However, they found social norms significant: if homeowners in the neighborhood installed hurricane shutters, most would follow suit; the same was true of purchasing insurance ((Kunreuther *et al*., 2009)). For municipal governments, adoption of building codes in hurricane prone areas reduces damages by $10 a square foot for homes built between 1996-2004 in Florida ((Kunreuther *et al*., 2009)). However, enforcement of building codes by municipalities is highly variable and becomes a limiting factor in disaster risk management and adaptation.

5.5. Management Strategies

There are a variety of strategies for managing disaster risk and adaptation to climate extremes at the local level. These range from baseline assessments of disaster risk to vulnerability assessments to social transfers. A few of the most utilized strategies by local actors and for local places are described.

5.5.1. Methods, Models, Assessment Tools

Prior to the development and implementation of management strategies and adaptation alternatives, local entities need baseline assessments on disaster risk and the likely impacts of climate extremes. The assessment of local disaster risk includes three distinct elements: 1) Exposure (risk) assessment, or the identification of hazards and their potential magnitudes/severities as they relate to specific local places; 2) Vulnerability assessments that identify the sensitivity of the population to such exposures and the capacity of the population to cope with and recover from them; and 3) Damage assessments that determine direct and indirect losses from particular events (either *ex -post* in real events or *ex-ante* through scenarios or modeling for hypothetical events). Each of these plays a part in understanding the hazard vulnerability of a particular locale or characterizing not only who is at risk but also the driving forces behind the differences in disaster vulnerabilities in local places.

There are numerous examples of exposure and vulnerability assessment methodologies and metrics ((Birkmann, 2006)). Of particular note are those studies focused on assessing the sub-national exposure to coastal hazards ((Gornitz *et al*., 1994; Hammer-Klose and Thieler, 2001)), drought ((Alcamo *et al*., 2008; Kallis, 2008; Wilhelmi and Wiilhite, 2002)), or multiple hazards such as FEMA's multi-hazard assessment for the United States ((FEMA, 1997)).

Vulnerability assessments highlight the interactive nature of disaster risk exposure and societal vulnerability. While many of them are qualitative assessments ((Birkmann, 2006) (Bankoff *et al*., 2004)), there is an emergent literature on quantitative metrics in the form of vulnerability indices. The most prevalent vulnerability indices, however, are national in scale ((Cardona, 2007; Cardona, 2007; Cardona, 2007; SOPAC and UNEP, 2005)) and compare countries to one another, not places at sub-national geographies. The exceptions are the empirically-based Social Vulnerability Index (or SoVI^{TM}) ((Cutter *et al*., 2003)) and extensions of it ((Fekete, 2009)).

Vulnerability assessments are normally hazard specific and many have focused on climate-sensitive threats such extreme storms in Revere, Massachusetts ((Clark *et al*., 1998), sea level rise in Cape May, New Jersey((Wu *et al*., 2002)) or flooding in Germany ((Fekete, 2009)) and the U.S. ((Burton and Cutter, 2008);(Zahran *et al*., 2008)). Research focused on multi-hazard impact assessments range from locally-based county level assessments for all hazards in Georgetown County, South Carolina ((Cutter *et al*., 2000)) to sub-national studies such as those involving all hazards for Barbados and St. Vincent ((Boruff and Cutter, 2007)) to those involving a smaller subset of climate-related threats ((Alcamo *et al*., 2008; O'Brien *et al*., 2004); (Brenkert and Malone, 2005)). The intersection of local exposure to climate-sensitive hazards and social vulnerability was recently assessed for the northeast ((Cox *et al*., 2007)) and southern region of the US ((Oxfam, 2009; Oxfam, 2009)).

However, the full integration of risk exposure and social vulnerability into a comprehensive vulnerability assessment for the local area or region of concern is often lacking for many places. Part of this is a function of the bifurcation of the science inputs (e.g. natural scientists provide most of the relevant data and models for exposure assessments while social scientists provide the inputs for the populations at risk) and the difficulties of working across disciplinary or knowledge boundaries.

5.5.2. Social, Financial, and Risk Transfers

5.5.2.1. Social Transfers

Social protection (SP) describes all public and private initiatives that provide income or consumption transfers to the poor, protect the vulnerable against livelihood risks, and enhance the social status and rights of the marginalised ((Devereux and Sabates-Wheeler, 2004)). These initiatives have the overall objectives of extending the benefits of economic growth, and reducing the economic and social vulnerability of poor, vulnerable and marginalised groups. These can be divided into *core* SP interventions, such as asset transfers, income transfers and public works, or *complementary* interventions, such as micro-credit services, social development, skills training and market enterprise programmes.

SP has risen significantly up the international policy agenda in recent years, partly due to the impacts of the global financial crises in the late 1990 and early and late 2000s on poor and marginalised people ((Davies and McGregor, 2009)(G20, 2009)). It is now becoming increasingly recognised that SP can play an important role in the delivery of pro-poor climate change adaptation and disaster risk reduction (DRR) assistance to vulnerable populations in developing countries ((Heltberg *et al*., 2010)(Stern, 2007; Stern, 2007)). Table 5-4 provides a summary of the SP measures and instruments, and associated adaptation and DRR benefits ((Davies *et al*., 2009a)).

[INSERT TABLE 5-4 HERE:
Table 5-4: Social protection measures and instruments, and associated adaptation benefits.]

As Table 5-4 shows, SP offers a wide range of benefits for adaptation and DRR, both in response to short-term climate disasters, as well as long-term risks posed by climate change. The concept of Adaptive Social Protection (ASP) provides a framework for the integration of SP, climate change adaptation and DRR into one coherent approach ((Davies and Leavy, 2007)). However, in spite of these conceptual advancements, there are only a few studies on the implications of SP implementation for dealing better with climate events. Of the studies that do exist, most have been conducted in South Asia ((Arnall *et al.*, 2009; Heltberg *et al.*, 2009)), although a number have also been completed in relation to individual safety net programmes in sub-Saharan Africa ((Devereux *et al.*, 2006)(Slater *et al.*, 2006)). According to Heltberg ((Heltberg *et al.*, 2009)), SP has formed an important part of the World Bank's disaster response in several major recent climate-related disasters in south Asia. Such support included direct cash to affected households, and workfare (cash-for-work). In Africa, preliminary lessons from Ethiopia's nation-wide Productive Safety Net Programme (PSNP), which assists the most chronically impoverished with cash transfers and cash-for-work schemes, reveal a positive effect on household food consumption ((Devereux *et al.*, 2006)) and a reduction in 'distress selling' of assets as well as the protection of household assets ((Slater *et al.*, 2006)). In these situations, proactive safety nets in the form of cash transfers and work programmes appear to present a viable alternative to traditional post-disaster relief responses. However, it is important to have such programmes in place before the onset of disasters, with flexible targeting, financing and implementation arrangements for scaling up as appropriate ((Alderman and Haque, 2006)), and prevention and risk management measures already integrated in ((Bockel *et al.*, 2009)).

Other social protection instruments used occasionally in disasters in south Asia are conditional cash transfers, near-cash instruments such as vouchers and fee waivers, social funds, and specific services such as child protection, orphanages, and rehabilitation for persons with disabilities ((Heltberg *et al.*, 2009)). In Bangladesh, recent experiences of asset restocking following disasters ((Marks, 2007)(Devereux and Coll-Black, 2007);(Tanner *et al.*, 2007)) demonstrate that such approaches can contribute to reducing vulnerability to climate shocks by providing liquidity and alternative sources of income during times of household stress ((Davies *et al.*, 2009b)). In addition, starter packs and seed fairs have revealed success in boosting food production at the national and household level ((Devereux and Coll-Black, 2007)). These have been more commonly used in Africa, although concern has been expressed that inputs sourced through commercial seed and fertiliser companies are sometimes inappropriate to local cropping patterns and agro-ecological conditions ((Davies *et al.*, 2009b)). Microcredits are another social protection measure (Ray-Bennett, 2010).

5.5.2.2. Insurance

Two types of insurance – formal/traditional and micro – serve the local population to spread stochastic losses geographically and temporally, and can assure timely liquidity for the recovery and reconstruction process. Insurance is an effective disaster risk reduction tool especially when combined with other risk management measures. For example, in most industrialized countries, insurance is utilized in combination with early warning systems, risk information and disaster preparation, and disaster mitigation. Where insurance is applied without adequate risk reduction, it can be a disincentive for adaptation, as individuals rely on insurance entirely to manage their risks and are left totally exposed to impacts ((Rao and Hess, 2009)). Furthermore, insurance can provide the necessary financial security to take on productive but risky investments ((Höppe and Gurenko, 2006)). Examples include a pilot project in Malawi where microinsurance is bundled with loans that enable farmers to access agricultural inputs that increase their productivity ((Hess and Syroka, 2005)), and a project in Mongolia that protects herders' livestock from extreme winter weather ((Skees *et al.*, 2008)).

Formal insurance is utilized extensively in the industrialized countries, where it covers around 40 percent of disaster losses ((Höppe and Gurenko, 2006)) to residents and businesses. In 2008, premiums as a percentage of GDP typically exceeded 5% in industrialized countries and up to as high as 15%. However, coverage is heterogeneous across countries and lines of business ((Vellinga, P., E. Mills, G. Berz, L. Bouwer, S. Huq, L.A. Kozak, J. Palutikof, B. Schanzenbacher,G.Soler, 2001)). This results from differential levels of exposure, regulatory and economic conditions and market characteristics, all of which affect local communities. In many industrialized countries, the public sector plays some role in insuring risks, either by taking a slice of the risk, for example providing a backstop or 'insurer of last resort' for the most extreme catastrophe risks, or by covering lines that are uninsurable at an affordable rate by the private market ((Vellinga, P., E. Mills, G. Berz, L. Bouwer, S. Huq, L.A. Kozak, J. Palutikof, B. Schanzenbacher,G.Soler, 2001)). The U.S., for example, has a federally-backed National Flood Insurance Program (NFIP) although it continues to run at a deficit.

Typically insurance coverage expands with economic growth. Penetration is currently growing rapidly in the emerging economies, where the rate of growth in insurance premiums (+15% per year between 1998 and 2008) has far outstripped that in the developed world ((Swiss Re, 2009)). In 2008, total premiums from emerging economies stood at just over $0.5 trillion USD. Swiss Re ((Swiss Re, 2008)) describes that in developing countries, insurance is most common among the commercial and industrial sectors and higher income groups. In the non-life industry, the bulk of premium volumes come from the motor sector, with property insurance a relatively low proportion (e.g. 20 percent in India). The penetration of agricultural insurance in developing countries is low despite its economic importance, with premiums accounting for only 0.01 percent of GDP. In 2008, global annual non-life premiums (which include property and casualty lines) stood at $1.8 trillion USD ((Swiss Re, 2009)). Insurance has a much lower penetration in developing countries; here it covers only around 3 percent of disaster losses ((Höppe and Gurenko, 2006)). This results from a lack of affordability and distribution channels, but also socio-cultural factors (e.g. many poorer societies utilize informal social safety nets). New types of insurance are being designed to service these lower income groups; for example, micro-insurance.

Microinsurance is a financial arrangement to protect low-income people against specific perils in exchange for regular premium payments ((Churchill, 2006; Churchill, 2007)). Several pilot projects have yielded promising outcomes, yet experience is too short to judge if microinsurance schemes are viable in the long haul for local places. Many of the ongoing microinsurance initiatives are index-based: a relatively new approach whereby the insurance contract is not against the loss itself, but against an event that causes loss, such as insufficient rainfall during critical stages of plant growth ((Turvey, 2001)). Weather index insurance is largely at a pilot stage, with several projects operating around the globe, including in Mongolia, Kenya, Malawi, Rwanda and Tanzania ((Hellmuth *et al.*, 2009)). In India, a weather insurance program grew from covering just 1,100 farmers in 2004 to insuring over 700,000 farmers by 2008. Index insurance for agriculture is more developed in India, where the Agricultural Insurance Company of India (AIC) has extended coverage against inadequate rainfall to 700,000 farmers.

Index-based contracts as an alternative to traditional crop insurance have the advantages of greatly limiting transaction costs (from reduced claims handling) and eliminating moral hazard (as there are no incentives to negligent behavior because claims are independent of the farmers' practices). A disadvantage is their potential of a mismatch between yield and payout, a critical issue given the current lack of density of meteorological stations in vulnerable regions – a challenge that remote sensing may help address ((Skees and Barnett, 2006)). Participants' understanding of how insurance operates, as well as their trust in the product and the stakeholders involved may also be a problem for scaling up index insurance pilots, although simulation games and other innovative communication approaches are yielding promising results ((Patt *et al.*, 2009)). Affordability can also be a problem: because disasters can affect whole communities or regions (co-variant risks), insurers must be prepared for meeting large claims all at once, with the cost of requisite backup capital potentially raising the premium far above the client's expected losses – or budget. While valuable in reducing the long-term effects on poverty and development, insurance instruments, particularly if left entirely to the market, are not appropriate in all contexts ((Linnerooth-Bayer, 2010)).

The insurance industry itself is vulnerable to climate change. Eighty-seven percent of insured losses events between 1985 and 1999 were weather-related ((Munich Re Group, 2000)). Research by the Association of British Insurers ((Association of British Insurers (ABI), 2005)) concluded that an increase of just 6 per cent in wind speeds could increase average annual insured property losses in the United States from hurricanes from US$5.5 billion to around US$9.5 billion. The continuing exit of private insurances is seen with the increasingly catastrophic local losses in the U.S. ((Lecomte and Gahagan, 1998)), UK ((Priest *et al.*, 2005)) and Germany ((Botzen and van den Bergh, 2008)(Thieken *et al.*, 2006)). Climate change could be particularly problematic in communities, which begin to see new types of risks for which they are unprepared. Vellinga *et al.* 2001 ((Vellinga, P., E. Mills, G. Berz, L. Bouwer, S. Huq, L.A. Kozak, J. Palutikof, B. Schanzenbacher,G.Soler, 2001)) overview a number of dimensions of insurer vulnerability that could be impacted by climate change, including: the probable maximum loss; and pressures from regulators responding to changing prices and coverage ((Kunreuther *et al.*, 2009)).

One response to rising levels and volatility of risk has been to increase insurance and reinsurance capacity through new alternative risk transfer instruments, such as index-linked securities (including catastrophe bonds) ((Vellinga, P., E. Mills, G. Berz, L. Bouwer, S. Huq, L.A. Kozak, J. Palutikof, B. Schanzenbacher,G.Soler, 2001)). Kunreuther and Michel-Kerjan ((Kunreuther *et al.*, 2009)) and others suggest that these tools could play an increasingly important role in a new era of elevated catastrophe risks. Another approach is to reduce risks through societal adaptation ((Herweijer, C., N. Ranger,R.E.T.Ward, 2009)). For example, Lloyds of London (2008) demonstrates that in exposed coastal regions communities increase in average annual losses and extreme losses due to sea level rise in 2030 could be offset through investing in property-level resilience to flooding or sea walls. Similarly, RMS ((RMS, 2009)) shows that wind-related losses in Florida could be significantly reduced through strengthening buildings. Given the clear benefits of adaptation for insurance, Ward et al. 2008 ((Ward, R.E.T., C. Herweijer, N. Patmore,R.Muir-Wood, 2008)) describes a number of ways in which insurers themselves can help to promote adaptation through risk communication and financial incentives.

5.5.2.3. Social and Environmental Outcomes

One of the key issues in examining outcomes of local strategies for disaster risk management and climate change adaptation is the principle of fairness and equity. There is a burgeoning research literature on the climate justice looking at the differential impacts of adaptation policies ((Adger *et al.*, 2006); (Kasperson and Kasperson, 2001)) at local, national, and global scales. The primary considerations at the local level are the differential impacts of policies on communities, subpopulations, and regions from present management actions (or inactions) ((Thomas and Twyman, 2005)). There is also concern regarding the impact of present management (or inactions) in transferring the vulnerability of disaster risk from one local place to another (spatial inequity) or from one generation to another (intergenerational equity) ((Cooper and McKenna, 2008)).

5.5.3. Adaptation as a Process

Experience in planning and implementing adaptation reveals that adaptation is a socio-institutional process bringing together a set of inter-twined elements ((Downing and Dyszynski, In press; Tschakert and Dietrich, In press)). O'Brien *et al.* ((O'Brien *et al.*, 2009)) focus on the process of adaptation and suggest an adaptation continuum (see Figure 5-4), where the first stage is to focus on the impacts. As local capacity increases, the progression from vulnerability to adaptation to development, to resilience ensues. Throughout the process, learning increases and institutions change and a paradigmatic transformation occurs—the community moves away from an impact-focus perspective to a resilience-centric one where there is an expectation of risk and where good governance and key partnerships are the norm.

[INSERT FIGURE 5-4 HERE:
Figure 5-4: Dimensions of the adaptation continuum (O'Brien *et al.*, 2009).]

A key component of the adaptation process is the ability to learn ((Armitage *et al.*, 2008; Lonsdale *et al.*, 2008; Pahl-Wostl *et al.*, 2007)). This focus on learning partly derives from the fields of social-ecological resilience and sustainability science ((Berkes, 2009; Kristjanson *et al.*, 2009)). The extension of social, participatory, and organizational learning to climate change adaptation has emphasized the significance of identifiable climate change signals, informal networks, and boundary organizations to enhance the preparation of people and organizations to the changing climate ((Berkhout, F., J. Hertin,D.Gann, 2006; Pelling, M., C. High, J. Dearing,D.Smith, 2008)). Participatory learning is especially emphasized ((Berkhout, 2002; Shaw, A., S. Sheppard, S. Burch, D. Flanders, A. Wiek, J. Carmichael, J. Robinson,S.Cohen, 2009; Shaw, A., S. Sheppard, S. Burch, D. Flanders, A. Wiek, J. Carmichael, J. Robinson,S.Cohen, 2009)). Focusing on what can be learnt from managing current climate risk is a good starting point particularly for poor and marginalized communities ((Someshwar, 2008)). As scenarios combine quantitative indicators of climate, demographic, biophysical, and economic change as well as qualitative storylines of socio-cultural changes at the local level, the participation of local stakeholders is essential to generate values and understandings of climate extremes.

If adaptation is a process rather than an end-point it requires a focus on the institutions and policies that enable or hinder this process ((Inderberg and Eikeland, 2009)) and the acknowledgement that there are often competing stakeholder goals ((Ziervogel and Ericksen, 2010)). Fostering better adaptive capacity for disaster and climate risk will help to accelerate future adaptation ((Inderberg and Eikeland, 2009; Moser, 2009; Patt, 2009)). However, there are barriers. These include lack of coordination between actors, and the complexity of the policy field hampering innovative approaches ((Mukheibir and Ziervogel, 2007; Winsvold *et al.*, 2009)). Limited human capacity to implement policies can also hamper adaptation ((Ziervogel *et al.*, 2010)), although individuals' perceptions of risk and adaptive capacity can determine whether adaptation responses are initiated or not ((Grothmann and Patt, 2005)).

5.6. Information, Data, and Research Gaps at the Local Level

The causal processes by which disasters produce systemic effects in chronological and social time is reasonably well-known and has been outlined by Kreps and others ((Cutter, 1996; Kreps, 1985; Lindell and Prater, 2003)(NRC (National Research Council), 2006; NRC (National Research Council), 2006)). Yet, local emergency management communities have by and large paid little attention to the links between climate change and natural hazards ((Bullock *et al.*, 2009)). As a result, state and local mitigation plans, even when required by law, usually fail to include climate change, sea level rise, or extreme precipitation in hazard assessments or do so in entirely deterministic ways.

Decisions about development, hazard mitigation, and emergency preparedness in the context of climate change give rise to critical social and economic adaptation questions. For example
Do increased levels of hazard mitigation and disaster preparedness increase risk taking by individuals and social systems? Do cumulative impacts of smaller events over time compare to single high impact events? How do short-term adjustments or coping strategies enable or constrain long-term vulnerabilities? What are the tradeoffs among decision acceptability versus decision quality?

The hurricane recovery process includes ample evidence of how efforts to ensure that the rush to "return to normal" have also led to depletion of natural resources and increased risk. How decisions regarding the right to migrate (even temporarily), the right to organize and the right of access to information are made will, as a result, have major implications for the ability of different groups to adapt successfully to floods, droughts, storms and the other consequences anticipated as a result of climatic change. The idea of linking place-based recovery, preparedness, and resilience to adaptation is intuitively appealing. However, the constituency that supports improved disaster risk management has historically proven too small to bring about many of the changes that have been recommended by researchers, especially those that focus on strengthening the social fabric to decrease vulnerability. Behind the specific questions of the transparency of risk, are broader questions about the public sphere. What public goods will be provided by governments at all levels (and how will they be funded), what public goods will be provided by private or organizations in civil society, what will be provided by market actors, and what will not? How will these influence local-level disaster risk management, especially to climate-sensitive hazards?

While there has been increasing focus on the processes by which knowledge has been produced, less time has been spent examining the capacity of local communities to critically assess knowledge claims made by others for their reliability and relevance to those communities ((Pulwarty, 2007)Fischoff, 1996). There is the need to move beyond the integration of physical and societal impacts to focus on practice and evaluation. How are impediments to the flow information created? Is a focus on communication adequate to ensure effective response? How are these nodes defined among differentially vulnerable groups e.g. based on economic class, race, gender? However, there is little research on the extent to which local jurisdictions have adopted policy options and practice and the ways in which it is being implemented. Most of the studies to date have addressed factors that lead to policy adoption and not necessarily successful implementation.

Beyond infrastructure and retrofitting concerns, successful adaptation strategies integrate urban planning, water management, early warning systems and preparedness. One widely-acknowledged goal is to address, directly, the problem of an inadequate fit between what the research community knows about the physical and social dimensions of uncertain environmental hazards and what society chooses to do with that knowledge. An even larger challenge is to consider how different systems of knowledge about the physical environment, and competing systems of action can be brought together in pursuit of diverse goals that humans wish to pursue ((Mitchell, 2003)). Several sources (Comfort, et al 2009; (Bullock *et al*., 2009; McKinsey Group, 2009)(McKinsey Group, 2009)) have identified key requirements for addressing these challenges, including developing:

1) Multi-way information exchange systems-effective adaptation will always be locally-driven. Communities need reliable measurements and assessment tools, integrated information about risks that those tools reveal and best approaches to minimize those risks. The goal is to develop a coordinated effort to improve the assessment and transparency of risk in a geographic place-based approach to vulnerable regions. Better locally-based data on economic losses, disaster and adaptation costs, and human losses (fatalities) will ensure improved empirically-based baseline assessments.
2) Maps of the decision processes for disaster mitigation, preparedness, response and recovery and guidance for using such decision support tools. Hazard maps are the simplest and often most powerful form of risk information. They capture the likelihood and impact of a peril and are important for informing risk reduction and risk transfer. Such devices would identify: specific segments of threatened social systems that could suffer disproportionate disaster impacts; critical actors at each jurisdictional level; their risk assumptions; their different types of information needs; and the design of an information infrastructure that would support their decisions at critical entry points Comfort ((Comfort, 1993)).
3) People who face hazards should be assisted to manage their own environments more responsibly and equitably over the long term by joining in a global structure that supports informed, responsible, systematic actions to improve local conditions in vulnerable regions. Governments and institutions can support, provide incentives, and legitimize successful approaches to increasing capacity and action.
4) Methodologies and measurement of progress in reducing vulnerability and enhancing community capacity at the local is under researched. Locally-based risk management, cost-effectiveness methodologies and analyses, investigation of societal impacts of catastrophic events at local to national scales, and research on implementation of risk management and mitigation programs are all needed. Similarly, there is a critical need for the assessment and coordination of multi-jurisdictional and multi-sectoral efforts to help avoid the unintended consequences of actions.
5) Underserved people require to access to the social and economic security that comes from sharing risk, through financial risk transfer mechanisms such as insurance. There is a paucity of studies at the local level to assess the efficacy of alternative risk reduction or transfer methods, analysis of benefits and costs to various stakeholder groups, analysis of complementary roles of mitigation and insurance, and analysis of safeguards against insurance industry insolvency.

Previous studies have identified community hazard vulnerability, community resources, and especially, strategies and structures that emergency managers and other hazards professionals can adopt at low cost. The knowledge to construct regional geographic information systems that provide the information base for indices is already available ((Maskrey, 1989; National Academy of Public Administration (NAPA), 1998)(Maskrey, 1989; National Academy of Public Administration (NAPA), 1998)). Nonetheless, most studies have relied on limited samples and need further work to replicate and extend their findings. Interdisciplinary collaboration is clearly needed to prioritize and address research tasks for bridging knowledge gaps in our understanding. These gaps include: analyses of vulnerability that integrate into their assessment the extent to which knowledge is framed, co-produced and utilized; factors that promote the adoption of more effective community level hazard mitigation measures and assessments of the effectiveness of hazard mitigation programs; development and local calibration of better models to guide long-term protective action decision making in emergencies; understanding impacts, response and recovery for near-catastrophic and catastrophic disaster events at the local level; research and support for risk-pooling mechanisms for small-scale production units; and understanding the role and benefits of ecosystems services in providing buffers for uncertain risks.

The experiences of extreme events and sequences of events considered in this chapter validate the notion of socially constructed disasters. Risk reduction and hazard mitigation strategies must address the underlying practices that contribute to vulnerability. The goal is to be clearer about existing conditions and projected changes e.g. weakening of bridges, levees and other structures due to long exposure to water of changing quality and other corrosives. These actions will situate the scientific understanding of hazard within a broader discourse about different forms of knowledge, and increase the likelihood of public actions that are better grounded in scientific knowledge and customized for the local context.

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Table 5-1: Guidelines for grey literature inclusion.

1. Results and conclusions that are substantiated by evidentiary material presented in the document.
2. Objective and non-biased reports that lack obvious and explicit motives such as seeking further funding or promoting a particular cause.
3. Original reports customized for the specific local setting and situation and not repetitious reports done for different settings/locales by the same consultant/and or agency with formulaic presentations and findings.
4. The material was useful for triangulation of key findings.
5. Regional reports on disaster risk management and climate change adaptation when no other information was available and when they met the above criteria.

Table 5-2: Local experience with climate extreme hazards based on number of reported disasters, 1999-2008.

	Africa	Americas	Asia	Europe	Oceania	Total
Droughts	127	51	75	16	3	272
Temperature extremes	5	40	50	108	1	204
Floods	402	342	649	259	43	1,695
Wildfires	12	61	20	51	10	154
Mass movements (wet)	12	34	111	18	5	180
Windstorms (cyclones)	88	344	401	160	69	1,062
Regional Total	646	872	1,306	612	131	3,567

Source: International Federation of Red Cross and Red Crescent Societies, 2009. World Disasters Report 2009. http://www.ifrc.org/publicat/wdr2009/summaries.asp

Table 5-3: Top five climate extreme hazards events, 1950-2009.

	Country	Date	Event	Estimated Loss
Fatalities				
	1. China	July 1959	Flood	2 million
	2. India	1965	Drought	1.5 million
	3. Ethiopia	May 1983	Drought	300,000
	4. Bangladesh	Nov 1970	Storm	300,000
	5. Sudan	Apr 1983	Drought	150,000
People Affected				
	1. India	May 1987	Drought	300 million
	2. India	Jul 2002	Drought	300 million
	3. China	Jul 1998	Flood	239 million
	4. China	Jun 1991	Flood	210 million
	5. India	1972	Drought	200 million
Economic Damages				
	1. USA	Aug 2005	Hurricane Katrina	125 billion
	2. USA	Sep 2008	Hurricane Ike	30 billion
	3. China	Jul 1998	Flood	30 billion
	4. USA	Aug 1992	Hurricane Andrew	26.5 billion
	5. China	Jan 2008	Extreme temp	21.1 billion

Source: http://www.emdat.be/disaster-profiles

Table 5-4: Social protection measures and instruments, and associated adaptation benefits.

SP measure	SP instruments	Adaptation and DRR benefits
Provision (coping strategies)	– social service protection – basic social transfers (food/cash) – pension schemes – public works programmes	– protection of those most vulnerable to climate risks, with low levels of adaptive capacity
Preventive (coping strategies)	– social transfers – livelihood diversification – weather-indexed crop insurance	– prevents damaging coping strategies as a result of risks to weather-dependent livelihoods
Promotive (building adaptive capacity)	– social transfers – access to credit – asset transfers/protection – starter packs (drought/flood resistant) – access to common property resources – public works programmes	– promotes resilience through livelihood diversification and security to withstand climate related shocks – promotes opportunities arising from climate change
Transformative (building adaptive capacity)	– promotion of minority rights – anti-discrimination campaigns – social funds	– transforms social relations to combat discrimination underlying social and political vulnerability

Source: Davies et al., 2009a

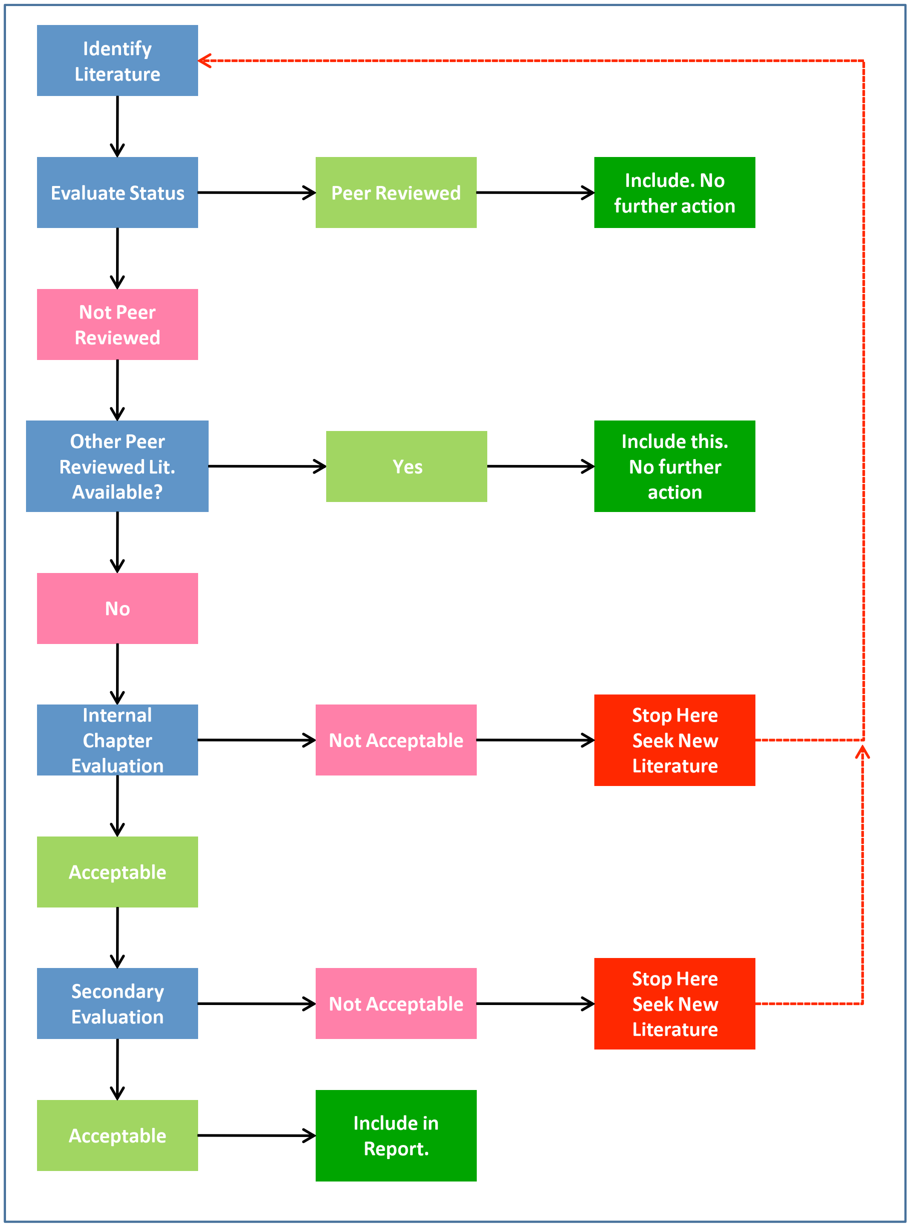

Figure 5-1: Procedure for assessing grey literature.

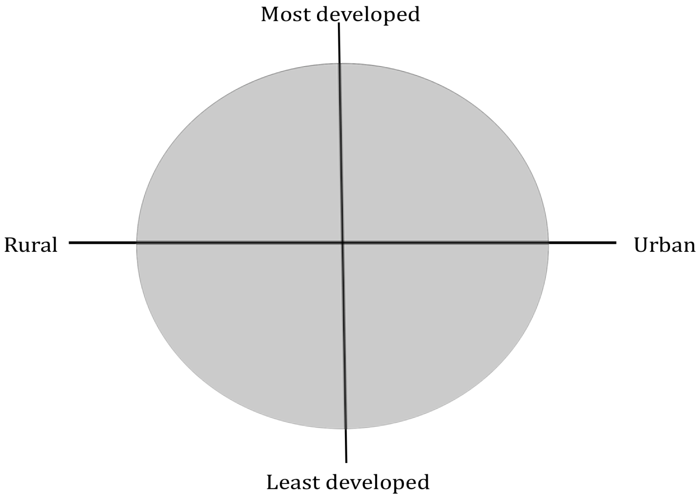

Figure 5-2: The Continuum of development and urbanization.

Figure 5-3: Earth embankment along the river (left) with stabilization (right) (ADPC, 2005).

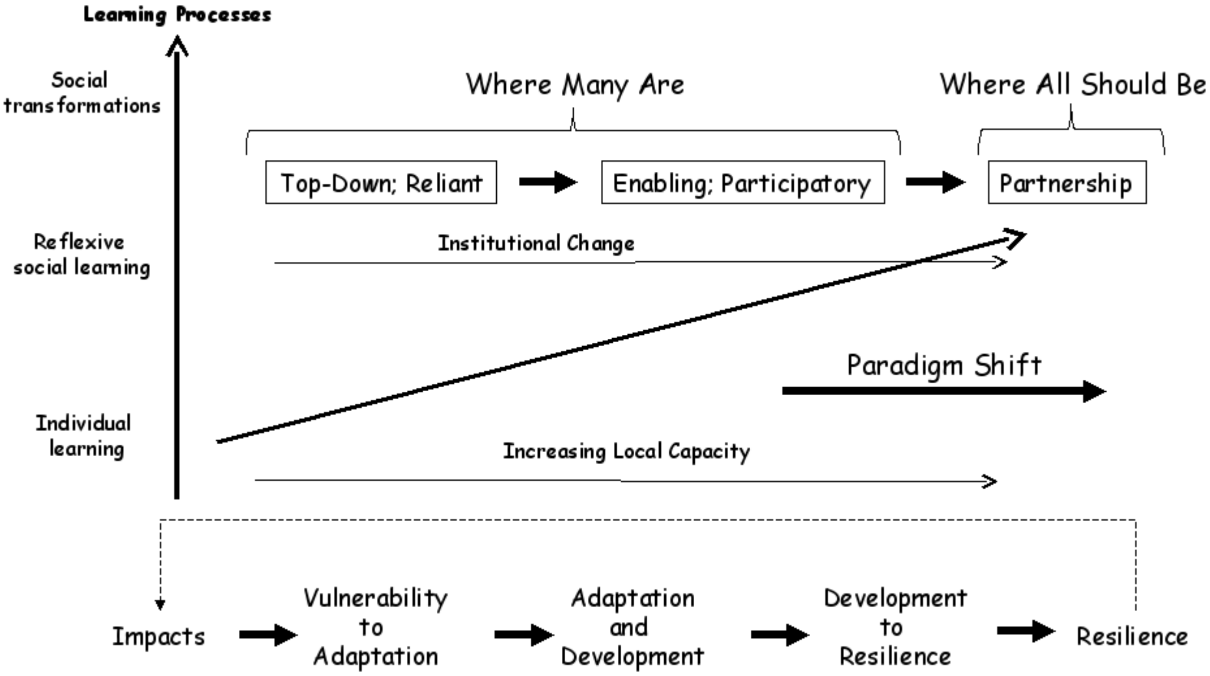

Figure 5-4: Dimensions of the adaptation continuum (O’Brien et al. 2009).

Chapter 6: National Systems for Managing the Risks from Climate Extremes and Disasters

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Contents

Executive Summary

This chapter examines the actors and functions that comprise national systems for managing the risks of climate extremes and disasters. It assesses how these systems can adapt to the challenges of changing hazards, risks and uncertainties associated with climate change and the trends in vulnerability and exposure highlighted in earlier chapters. This chapter recognizes that effective national systems involve actors playing differential but complementary roles according to their accepted functions and capacities across geographical scales, time and levels of society. These actors include national and sub-national governments, private sector, research, civil society and community-based organizations and communities, ideally working in partnership and harmony to cost effectively support people's efforts to reduce their risks and vulnerabilities. Well designed national systems would cover the full range of activities associated with managing climate extremes and disaster risks including supporting efforts to reduce risks, transfer risks and responding efficiently to disaster impacts as well as adapting to changing risk attributable to climate change and other factors. However, developed and developing countries alike consistently demonstrate their inability to tackle current disaster risks albeit to different degrees and this existing adaptation deficit must be tackled together with the new challenges posed by climate change. Governments at all scales play a crucial role achieving this aim.

In many countries national and sub-national government agencies initiate and lead many of the disaster risk management functions within their national system and play multiple roles in managing the risk of climate extremes and disasters. These functions include building and developing policy, regulatory and institutional frameworks that prioritize risk reduction; integrating disaster risk management with other policy domains like development or climate change adaptation; enabling different sectors and actors, as well as different levels of society, to be included in disaster risk management systems (6.3.1.1 and 6.3.1.2, 6.3.1.3); providing goods and services necessary for management disaster risks and climate extremes, including research and public awareness related to disasters, education, training (6.2.5, 6.3.1.1), such as early warning systems (6.3.3.1.2), and measures to support the most vulnerable in the society(6.3.1.4). Some national systems might organise and allocate responsibilities for functions more formally; others are constituted by actors fulfilling functions where they see gaps (6.2.2; 6.2.3; 6.2.4; 6.2.5). Many systems are not adequately coordinated, harmonised and appropriately sequenced for effective risk management (6.2.1; 6.3.1; 6.3.2; 6.3.3).

In some countries, where governments are weak, unwilling or unable to extend their reach to all people, social groups and areas of the country, other actors, particularly CSOs and multi-lateral organisations undertake a greater proportion of these functions (6.2.3; 6.2.4). The private sector, too, plays, an important role in managing disaster risk and adapting to climate change, particularly in the area of risk financing including insurance. While disaster insurances cover no more than a third of the global losses, and there are market failures and market gaps involved in the supply and demand for risk transfer instruments, risk financing mechanisms demonstrate substantial potential in both developed and developing world for absorbing a part of the financial burden of disasters (6.2.2, 6.3.2.2). It is though uncertain as to the extent to which the private sector could continue to play this role in the context of changing climate as they are often not willing to underwrite additional risks due to uncertainty and the presence of imperfect information, missing and misaligned markets and financial constraints. Innovative private-public sector partnerships are being explored in both developed and developing countries, with funding support from development partners a critical variable in developing countries (6.3.3.4).

Globally, different combinations of methods and tools have been used by countries to address disaster risk management challenges, with varying degrees of success in developed as well as developing countries, including using deterministic and probabilistic risk assessment techniques (6.3.3.1.1), increasing preparedness for disasters through education, training and early warning systems (6.3.3.1.2), adopting technological and infrastructure options (6.3.3.2.1), and investing in natural capital and ecosystem based adaption (6.3.3.2.3). Globally, governments and the private sector are working to develop innovative ways to transfer risk as well as share risks (6.3.3.3). Governments with the help of development partners are also beginning to explore alternative ways of supporting disaster risk management by addressing the underlying drivers of vulnerability, including the targeting of pro-poor development strategies for the most vulnerable groups of society (6.3.3.2.2) and insuring public sector relief expenditure (6.3.3.3).

With climate change altering the frequency and magnitude of some extreme events and helping to create more extreme impacts through amplifying vulnerability and exposure and increasing uncertainty in some areas (see Chapters 3 and 4), the efficacy of national systems requires review to not only address the current gaps in disaster risk management but also the affects of climate change on future disaster risks.

Ideally, national systems for managing the risks from climate extremes and other disasters would need to be redesigned by fully integrating development, environmental and humanitarian dimensions, appropriately designing, coordinating and sequencing disaster risk reduction strategies, including social protection and climate change adaptation, and recalibrating the differential roles played by national and sub-national governments, private sectors and communities. No country, developed or developing, can achieve this instantaneously, but rather may progressively move towards such a system by aligning existing national disaster risk management systems to the challenges of more frequent and extreme events of higher intensity, growing uncertainty and changing patterns of vulnerability and exposure. This alignment could include making incremental changes to disaster risk management policies, enabling environments, plans and actions by adopting adaptive management and learning by doing to reflect changing climatic conditions, uncertainties and nonlinearity in climate change, improving information and knowledge, as well as building individual and institutional capacity within socio-ecological-economic systems to deal with shocks (6.4.2). Acknowledging pre-disaster efforts have a higher payoff than responding to post disaster events, addressing climate change would also require greater attention to tackling the underlying drivers of current and increasing vulnerability under changing climate by focusing on policy instruments that that bring disaster risk reduction and climate change adaption benefits amongst the poorest in the society (6.4.3) as well as promoting low-carbon development (6.4.4).

6.1. Introduction

The socioeconomic impacts of disasters can be significant in all countries, but low and middle income countries, and it is especially the vulnerable within these countries, that often suffer the most. For example, during the quarter century (1980-2004) over 95% of natural disaster deaths occurred in developing countries, and fatalities per event were higher by orders of magnitude in low-and middle-income countries compared with high-income countries and losses as a percentage of gross national income (GNI) were also highly negatively correlated with per capita income (see Munich Re, 2005). For example, low-income, small island development states, such as Samoa and Vanuatu, suffer an average economic loss during disaster years of 46% and 30% of their GDP respectively (Bettencourt et al 2006).

Many highly exposed developing countries often cannot raise sufficient capital to replace or repair damaged assets and restore livelihoods following major disasters due to a lack of insurance, combined with reduced tax bases, high levels of indebtedness and limited donor assistance, exacerbating the impacts of disaster shocks on poverty and development. Over the last years, a growing literature has shown important adverse macroeconomic and developmental impacts of natural disasters (Cochrane 1994; Otero and Marti, 1995; Benson, 1997a,b,c; Benson, 1998; Benson and Clay, 1998, 2000, 2001; ECLAC 1982, 1985, 1988, 1999, 2002; Murlidharan and Shah, 2001; Crowards, 2000; Charveriat, 2000; Mechler, 2004; Hochrainer, 2006; Noy, 2009). These include reduced direct and indirect tax revenue, dampened investment and reduced long-term economic growth through their negative effect on a country's credit rating and an increase in interest rates for external borrowing. With exceptions, which consider disasters rather a problem of, but not for development (Albala-Bertrand, 1993, 2006; Caselli and Malhotra, 2004), this body of evidence proves that natural disasters can be a setback for development in the short- to medium-term. In turn, poor development status of communities and countries increases their exposure to disasters. Disaster impacts can also force households to fall below the basic needs poverty line, further increasing their vulnerability to other shocks (Lal et al 2009).

As a response to the impacts of disasters on countries' economies, on levels of poverty and broader development trajectories, many national governments have developed national systems for tackling climate extremes and disaster risks. These are desirable, not just as a response to the factors listed above, but also because governments have a responsibility and moral duty to their citizens and while they cannot act alone, the majority of governments are comparatively best equipped to tackle disaster risk. It is at national level that overarching development processes are generally put in place, albeit in varied forms and decisions on significant resource allocations occur (see Section 6.2.1 'role of national and sub-national government agencies in national systems'). National level governments are often called "insurers of last resorts" and "the most effective insurance instruments of society" (Priest 1996:225) as the governments are often the final entity that households and firms turn to in case of needs.

National level government also has the ability to mainstream consideration of extremes associated with climate variability and change into existing disaster risk management and development sectors, policies and plans. These include initiatives to assess risks and uncertainties, manage these across sectors, share and transfer risks and establish baseline information and research priorities (Prabhakar *et al*. 2008; Mechler 2004). In theory, national level institutions are best able to respond to the challenges of planned adaptation to extremes, given that disaster are largely covariate in nature, often surpassing people's and businesses' coping capacity (OAS, 1991; Otero and Marti 1995; Benson and Clay, 2002). National government decisions often pertain to longer time horizons and are amenable to better appreciate key uncertainties and risks associated with climate change (Priest, 1996; Hallegate, 2009). In many cases, it is at this national level that national systems for adapting to climate change and changing disaster risks will emerge.

With this in mind, valuable lessons for advancing adaptation to climate change can be drawn from existing national systems for managing the risks from climate extremes and disasters. These systems are comprised of actors operating across scales, fulfilling a range of functions, guided by an enabling environment of institutions, international agreements and experience of previous disasters. These systems vary considerably between countries in terms of their capacities and effectiveness and in the way responsibilities are distributed between actors. They also vary in how much emphasis they place on integration with development processes, tackling vulnerability and reducing disaster risk, compared with preparing for and responding to extreme events and disasters. As detailed in Chapters 3 and 4, climate change poses new challenges for these systems, which in many instances remain poorly adapted to the risks posed by existing climatic variability and extremes. Closing this adaptation deficit (Burton, 2004) and responding to the effects of climate change on disaster risk are seen as priorities for national risk management systems and as a crucial aspect of countries responses to climate change. With a history of managing the extremes of climate variability, a stronger institutionalisation across scales, including to the local level, a greater number of experienced actors and more widespread instances of supporting legislation and cross-sectoral co-ordinating bodies, national systems for managing disaster risks and climate extremes offer a promising avenue for supporting adaptation to climate change.

However, despite significant recent progress in developing national systems and despite the burden of disasters imposed and increasingly recognized, measures to reduce the risks of disasters are still insufficiently taken, and there is, for the most part, a continued reliance on post disaster response and disaster management support. For example, countries, donors and international financial institutions allocate about 90% of their disaster management funds for relief and reconstruction and, only about 10% of the funds for disaster risk management (Tearfund, 2006). This low level of investment in preventing disasters can be explained inter alia by a lack of understanding and concrete evidence regarding the types and extent of the cost and benefits of measures to reduce disaster risk (Benson and Twigg, 2005). National level decision-makers generally seek information on the costs and benefits of disaster risk reduction and adaptation options in order to motivate and defend investments in these measures. Yet, only a very limited number of studies looking at sub-national level disaster risk reduction and adaptation measures have demonstrated that disaster prevention and adaptation can pay high dividends. Studies such as Mechler (2005) and MMC (2008) found that for every dollar invested in risk management broadly, two to four dollars are returned in terms of avoided or reduced disaster impacts on life, property, the economy and the environment. In the absence of concrete information on net economic and social benefits, measures to reduce disaster risk are faced with limited budgetary resources and many policy makers have been reluctant to commit significant funds for risk reduction. However, certainly internationally, they are happy to continue investing considerable funds into high profile, post-disaster response (Benson and Twigg, 2005).

While the current lack of emphasis on risk reduction compared to response highlights the inadequacies of existing systems, there are nevertheless a host of success stories and promising initiatives for managing and reducing the risks of climate extremes and disaster that provide valuable guidance for advancing adaptation to climate change. Accordingly, this chapter assesses the literature on national system for managing disaster risks and climate extremes, particularly the design of such systems and the actors and functions involved. It reflects on the adequacy of existing knowledge, policies and practices and considers the extent to which they will need to evolve to deal with the effects of climate change on disaster risks and uncertainties. Section 6.2 characterises national systems for managing existing climate extremes and disaster risk by focusing on the actors that help create the system - national and sub-national government agencies, bi-lateral and multi-lateral organisations, private sector, research, civil society and community-based organisations. Drawing on a range of examples from different countries, Section 6.3 describes what is known about the status of managing current and future risk, what is possible in an effective national system and what gaps in knowledge exist. It is organised by the set of functions undertaken by the actors discussed in 6.2 and is divided into three main categories – those associated with planning and policies (Section 6.3.1), strategies (Section 6.3.2) and practices, including methods and tools (Section 6.3.3). Section 6.4 reflects on how national systems for managing climate extremes and disaster risk can become more closely aligned to the challenges of climate change and development – particularly those associated with uncertainty, changing patterns of risk and exposure, the impacts of climate change on vulnerability and poverty and the potential benefits of low-carbon, resilient forms of development. Many aspects of Section 6.4 are further elaborated in Chapter 8.

6.2. National Systems and Actors for Managing the Risks from Climate Extremes and Disasters

Managing climate-related disaster risks is everyone's business, from national and sub-national governments, private sector, research, civil society and community-based organizations and communities working in partnership to ultimately help individual households to reduce their risks and vulnerabilities (Twigg, 2004, ISDR 2009). For an effective and efficient national system for managing climate-related disaster risks each actor would ideally play differential but complementary roles according to their accepted functions and effectiveness across geographical scales, time and levels of society, supported by relevant scientific and traditional knowledge (ISDR, 2008). This section assesses the roles played by different actors working within such national systems.

6.2.1. National and Sub-National Government Agencies

National governments have the moral and legal responsibility to ensure economic and social well being, including safety and security, of their citizens from national disasters. It is also government's responsibility to protect the poorest and most vulnerable citizens from disasters, and to implement disaster risk management that reach all, especially the most vulnerable (McBean, 2008; O'Brien *et al.*, 2008; CCCD, 2009). In terms of risk ownership and responsibility, government and public disaster authorities "own" a large part of current and future extreme event risks and need to govern and regulate risks owned by other parts of society (Mechler, 2004).Recourse to various normative theories may be taken. As one example, economic welfare theory suggests that national governments are exposed to natural disaster risk and potential losses due to their three main functions: allocation of public goods and services (e.g. education, clean environment and security), the redistribution of income as well as their role in stabilizing the economy (see Musgrave, 1959). The risks faced by governments include the risk to losing public infrastructure and assets. National level government also generally redistribute income across members of society and thus are called upon when those are in need (Linnerooth-Bayer and Amendola, 2000), such when in danger of slipping into poverty, and in need of relief payments to sustain a basic standard of living, especially in countries with low per capita income and/or have large proportions of the population in poverty (Cummins and Mahul, 2008). Finally, it can be argued that governments need to stabilize the economy, e.g. by demand side interventions, when it is in disequilibrium. National level government are often called "insurers of last resort" as the governments are often the final entity that private households and firms turn to in case of need. It may well be suggested that most national governments would generally accept those normative functions, yet their degree of compliance and ability to honour those responsibilities differs significantly across countries.

In the context of a changing climate, governments have a particularly critical role to play in relation to not only addressing the current gaps in disaster risk management but more importantly in response to uncertainties and changing needs due to increase in frequency, magnitude and duration of some climate extremes (Katz and Brown, 1992; Meehl *et al.*, 2000; Christensen *et al.*, 2007).

Different levels of governments – national, sub-national and local level governments as well as respective sectoral agencies play multiple roles in addressing drivers of vulnerability and managing the risk of extreme climate events, although their effectiveness varies within a country as well as across countries. They are well placed to create multi-sectoral platforms to guide, build and develop policy, regulatory and institutional frameworks that prioritize risk reduction (Sudmeier-Rieux *et al.*, 2006; Handmer and Dovers, 2007); integrate disaster risk management with other policy domains like development or climate change adaptation (ISDR, 2004, 2009; White et al., 2004; Tompkins *et al.*, 2008); and address drivers of vulnerability and assist the most vulnerable populations (McBean, 2008; CCCD, 2009). Governments across sectors and levels also provide many public goods and services that help address drivers of vulnerability as well as those that support disaster risk management (White *et al.*, 2004; Shaw e*t al.*, 2009) through education, training and research related to disasters (Twigg, 2004; McBean, 2008; Shaw *et al.*, 2009). Governments play particularly a critical role in disaster risk management through the allocation of financial and administrative resources, and also with political authority (Spence, 2004; Handmer and Dovers, 2007; CCCD, 2009). Governments also has an important role to play in creating appropriate frameworks and enabling environment for the private sector, civil society organisations and other development partners to play their differential roles in managing disaster risk(O'Brien *et al.*, 2008; Prabhakar *et al.*, 2008). Such functions of national and sub-national governments are discussed further in Section *6.3 Functions of the national disaster risk management systems.*

6.2.2. Private Sector Organisations

Some aspects of disaster risk management may be suited for non-government stakeholders to implement, albeit this would ideally be coordinated within a framework created by governments. Private sector already plays an important role in DRM and adaptation, particularly in the area of risk financing and insurance. Despite complexities and uncertainties involved on supply and demand for risk transfer, risk financing mechanisms have been found to demonstrate substantial potential in both developed and developing world for absorbing the financial burden of disasters (e.g., Pollner, 2000; Andersen, 2001; Varangis, Skees and Barnett, 2002; Auffret, 2003; Dercon, 2005; Linnerooth-Bayer et al. 2005; Hess and Syroka, 2005; World Bank, 2007; Skees, 2008; Cummins and Mahul, 2008; Hess and Hazell,,2009). The extent to which the private sector would continue to play this role in the context of changing environment is though unclear due to uncertainty and imperfect information, missing and misaligned markets and financial constraints (see Smit et al., 2001; Aakre et al., 2010). Private insurers are often not prepared to underwrite insurance (Carpenter, 2000) the risks associated with variability and extreme events due to climate change, thus requiring innovative private-public sector partnerships supported by, in developing countries development partner funds as well (see Section 6.3.3.3 *Transferring and sharing 'residual risks').*

6.2.3. Civil Society and Community-Based Organisations (CSO and CBOs)

Implementation of some disaster risk management initiatives may be more cost effectively delivered through civil society organizations, particularly where governments are weak, and or have limited resources to reach particularly the marginal and poor communities (Benson, 2001). Civil societies have always played a critical role in humanitarian support, although more recently they have become more active in the field of disaster risk reduction and climate change adaptation (ISDR 2008; Oxfam America 2008; Practical Action Bangladesh 2008; Tearfund 2008; World Vision 2008)). Such expansion of roles has coincided with the increase in frequency and severity of disasters (Wilchez-Chaux, 2008), providing a variety of services including training, preparedness, food security, environment, housing and microfinance (Benson, 2001). In Latin America, disasters provoked by hurricanes Georges and Mitch in 1997 and 1998, respectively; as well as the impacts of El Niño South Oscillation in the years 1997-1998, led several CSO to respond and assist affected communities (Lavell 2001, Girot, 2000). CSO initiatives in the field of disaster risk management while may usually begin as humanitarian concerns, but often evolve to also embrace the broader challenge of disaster risk reduction following community focused risk assessment, including specific activities targeting education and advocacy, environmental management; sustainable agriculture; infrastructure construction, as well as increased livelihood diversification (McGray, et al., 2007,Care International 2008; Oxfam America 2008; Practical Action Bangladesh 2008; SEEDS 2008; Tearfund 2008; World Vision 2008).

While effective at the local level, the biggest challenge for CSO though remains securing resources for replicating successful initiatives and scaling out geographically (Care International 2008; Oxfam America 2008; Practical Action Bangladesh 2008; SEEDS 2008; Tearfund 2008; World Vision 2008); supporting capacity development to replicate and sustain projects (Care International 2008; Oxfam America 2008); sustaining commitment to work with local governments and stakeholders over long term and maintaining partnerships with local authorities, for example in Bangladesh (Oxfam America 2008), and coordinating and linking local level efforts with sub-national government initiatives and macro-level plans during the specific project implementation, for example in India (SEEDS 2008). Much of civil society initiatives are though critically dependent on support from external bilateral and multilateral agencies.

6.2.4. Bi-Lateral and Multi-Lateral Agencies

In developing countries, particularly where the government is weak and has limited resources, bilateral and multilateral agencies are major players in supplying financial and technical support to government and non-government agencies to tackle multifaceted challenges of disaster risk management and more recently climate change challenges. In managing climate-related risks, donor agency with multiple recipient countries, may take a pragmatic approach to delivering regionalised support given that extreme climatic events normally occur contiguously within specific region, such as across Pacific Islands, Southeast Asia and regions of Africa and Latin America. This also strengthens the role of regional agencies charged with helping countries manage climate extremes and disaster risks, such as SOPAC and SPREP in the Pacific (Gero, Méheux et al. 2010; Hay 2010).

Many bilateral and multilateral agencies though continue to address disaster risk management and climate change adaptation separately, linking with respective regional and national agencies and those associated with respective international instruments (Gero et al 2010). However, it is increasingly expected that multilateral and bilateral assistance is provided to support nationally-owned strategies, development plans and disaster risk management policies, though many such strategies, policies and plans still tend to treat climate change and disaster risks separately and predominantly focus on the response and preparedness dimensions of managing disaster risk.

Consequently, bilateral and multilateral agencies often adopt different approaches and modalities to supporting different dimension of risk management and climate change adaptation. This in itself is not a bad thing – particularly in countries with weak delivery capacity at the local level supporting a diversity of stakeholders and approaches can help to ensure progress – for example through supporting local level NGOs and CBOs, along with government agencies. However, the critical challenge in such situations becomes that of coordination. Ultimately, a lack of effective coordination, including amongst external partners, often results in competing approaches and priorities and an unnecessary burden on government. While coordination of effort in countries are expected to be guided under national action plans for adaptation and disaster risk management, these have not necessarily been acted on in a coordinated manner, largely because of policy and funding gaps (Wickham, Kinch et al. 2009; Hay 2010). This situation is improving,, for example in the Pacific; countries are using their prioritised national action plan to engage with development partners to appropriately sequence and coordinate the support (Hays 2010). Countries, too, are trying to use national action planning processes on climate change and disasters to better coordinate their own as well as development partners support and resource allocation. This is being achieved through their budgetary allocation processes as well as with coordinating requests coming from sub-national to national levels.

6.2.5. Scientific and Other Research Organisations

The effectiveness of national systems for managing climate extremes and disasters risks is highly dependent on the availability and communication of robust and timely scientific information (Sperling and Szekely 2005; Thomalla et al. 2006) and traditional knowledge (ISDR 2008) to not only communities but also amongst researchers, and researchers and policy makers who manage national approaches to disaster risk and climate change adaptation.

Scientific and research organisations range from specialised research centres and universities, regional organisations, to national research agencies, multilateral agencies and NGOs playing differential roles, but generally continue to divide into disaster risk management or climate change adaptation communities. Scientific research bodies play three important roles in managing climate extremes and disaster risks by: (a) supporting thematic programmes to study the evolution and consequences of past hazard events, such as cyclones, droughts, sandstorms and floods; (b) analysing time- and space-dependency in patterns of weather-related risks; and (c) building cooperative networks for early warning systems, modelling, and long-term prediction. Disaster practitioners largely focus on short term climate forecasting and effective dissemination and communication of hazard information and responses (Thomalla et al 2006). Such climate change expertise can typically be found in environment or energy departments and in academic institutions (Sperling and Szekely 2005), while disaster risk assessments have been at the core of many multilateral and civil society organisations and national disaster management authorities. In addition, some agencies, particularly universities may be actively engaged in technical capacity building and training, or as in the case of largely civil societies in translating scientific evidence into adaptation practice, collating traditional knowledge, and lessons learnt for wider dissemination; or translating scientific information into user-friendly forms for community consumption (Sperling and Szekely 2005; Thomallaet al. 2006).

6.3. Functions of National Systems for Managing the Risks from Climate Extremes and Disasters

As Section 6.2 highlighted, national systems are comprised of a range of actors, undertaking certain functions and with varying success, cover the full range of disaster risk management activities, from managing uncertainty and reducing risk to responding to the impacts of climate extremes and disasters. It is important to recognise that in many countries national and sub-national government agencies initiate and lead many of the functions within the national system. However, in some countries, where governments are weak, unwilling or unable to extend their reach to all people, social groups and areas of the country, other actors, particularly CSOs and multi-lateral organisations undertake a greater proportion of these functions (see Section 6.2). Furthermore, some national systems might organise and allocate responsibilities for functions more formally; others are constituted by actors fulfilling functions where they see gaps. However, even where governments are weak or unwilling, it is important to continue efforts to strengthen national government capacity to lead national risk management systems (OECD 2010), given that managing disaster risk is primarily a government’s responsibility and governments have the potential to deliver and implement at the greatest scale.

The functions of national systems for managing the risks of climate extremes and disasters are multidimensional across actors and scales. As detailed in 6.2, national and sub-national governments having the primary responsibility of creating the enabling environment for other actors and its own agencies to reduce risk, share and transfer risk and manage residual risk. By drawing on a range of cases from different developed and developing countries, this section describes what is known about the status of managing current and future risk, what is possible in an effective national system and what gaps in knowledge exist. It is organised by the set of functions undertaken by the actors discussed in 6.2 and is divided into three main categories – those associated with planning and policies (Section 6.3.1), strategies (Section 6.3.2) and practices, including methods and tools (Section 6.3.3).

6.3.1. Planning and Policies for Integrated Risk Management, Adaptation, and Development Approaches

The management of climate and disaster risks today and into the future is a cross-cutting process that requires leadership, planning and coordination of policies at all levels of government, but especially at the national level (ISDR, 2009; CCCD, 2009). Since countries vary greatly in their political, cultural, socio-economic and hazards environments, disaster risk management and climate change adaptation plans and policies at the national scale will vary from country to country but will all need to consider the roles of sub-national and local actors (CCCD, 2009; ISDR, 2007). In spite of differences and given that learning will come from doing, there are many ways that countries can learn from each other in prioritizing their climate and disaster risks and in mainstreaming climate change adaptation and disaster risk management into plans, policies and development paths (UNDP, 2002). This sub-section will address frameworks for national disaster risk management and climate change adaptation planning and policies (6.3.1.1), the mainstreaming of plans and policies nationally (6.3.1.2) and the various sectoral disaster risk management and climate change adaptation options available for national systems (6.3.1.3).

6.3.1.1. Developing and Supporting National Planning and Policy Processes

National scale government agencies and other actors have a range of planning and policy options to help create the enabling environments for departments, public service agencies, the private sector and individuals to act (UNDP, 2002; Heltberg et al, 2009; OECD, 2009*).* When considering risk management and adaptation actions, it is often the scale of the potential climate and disaster risks and impacts, the capacity of the governments or agencies to act, the level of certainty on future changes and the timeframes within which these future impacts and disasters will occur that play an important role in their prioritization and adoption (Heltberg et al, 2008; World Bank, 2008b). For example, in countries and sectors with little capacity to deal with existing disasters or where the impacts of future changes remain highly uncertain, the planning and policy option of “no regrets” actions initially may offer the most realistic path for the future (UNDP, 2002; World Bank, 2008b; Heltberg et al, 2009). “No regrets” adaptation options imply that the benefits of the option are justified irrespective of whether the impacts to future climate change occur while “low regrets” options tend to “hedge” by dealing today with the uncertainties of the future changes through investments in research and outreach (Agrawala and van Aalst, 2008; OECD, 2009; Prabhakar et al, 2009). Improving the capacity of communities, governments or regions to deal with current climate vulnerabilities will likely also improve their capacity to deal with future climatic changes, particularly if such measures take a dynamic approach and can subsequently be adjusted to deal with further changes in climate risks and vulnerabilities (Sperling and Szekely, 2005).

Medium and high “regret” adaptation options include those that deal directly with the changing climate through plans and policies. These options are more likely to be considered when planning major large-scale projects where potential climate impacts are significant or irreversible and when the country has capacity to deal with the risk. The medium and high “regret” adaptation options include proactive planned adaptation to climate change and “triple-win” actions that have greenhouse gas reduction, disaster risk management, climate change adaptation and development synergies (Heltbert et al, 2009; Ribeiro et al, 2009; World Bank, 2008b). Many of these “win-win” options involve ecosystem management or ecosystem-based adaptation actions, sustainable land use and water planning, carbon sequestration, energy efficiency and energy and food self-sufficiency. In many cases, risk sharing can be considered a viable policy, including options such as insurance, micro-insurance and micro-financing, government disaster reserve funds and government-private partnerships involving risk sharing (Linnerooth-Bayer and Mechler, 2006; World Bank, 2010). These risk sharing options provide much needed, immediate liquidity after a disaster, allow for more effective government response, provide some relief of the fiscal burden placed on governments due to disaster impacts and constitute critical steps in promoting more proactive risk management strategies and responses (Arnold, 2008). Finally the option of “bearing the residual losses” is a choice for consideration when uncertainties over the direction of future climate change impacts are high, when capacity is very limited, adaptation options are currently not available or the impacts are low (Linnerooth-Bayer and Mechler, 2006; Heltberg et al, 2009; World Bank, 2010). All of these policy and planning options are particularly relevant at sectoral level where governments either define enabling environments for development projects to occur or define risks that are shared and transferred to be borne by different parts of society.

6.3.1.2. Mainstreaming Disaster Risk Management and Climate Change Adaptation into Sectors and Organisations

National planning and policies processes need to create an enabling environment where disaster risk management and climate change adaptation can be tightly linked with ongoing development efforts, involve stakeholders at all levels and spatial scales and create a culture of safety and resilience in everyday affairs (Mercer 2010; Litman 2008). Success will largely depend on the ability of national governments to align and integrate fiscal planning actions supporting disaster risk management and climate change adaptation and their ability to integrate climate risks into policies and into development decisions (ISDR 2009; Vogel 2009; Rosenzweig et al. 2007). Many studies indicate that one of the best ways to mainstream climate change into disaster risk management and development planning is to understand current climate impacts, consider potential impacts into the future and address both current and future impacts in development and risk reduction planning and policies (Prabhakar et al, 2009; UNDP, 2002; CCCD, 2009).

The existing barriers to managing the risks associated with current climate variability need to be addressed because it will help prepare for tackling the even greater barriers that may inhibit nations from addressing their future climate disaster risks (UNDP, 2002; UNDP, 2004). Some of the challenges to mainstreaming both disaster risk management and climate change adaptation into plans and policies, including risk assessments, early warning systems, sector risk management, insurance tools and public education, lie with government "silo" approaches, differing timeframes of interest for adaptation and risk reduction, the uncertainties of future climate scenarios as well as the need of each for relevant regional information on changing climate hazards and risks (Basher, 2009; ISDR, 2009; Wilby and Dessai, 2010). For example, environment or energy authorities as well as scientific institutions typically have responsibilities for climate change adaptation while authorities for disaster risk management reside with civil defence, disaster management or home affairs (Prabhakar et al, 2009; Thomalla, 2006; Sperling and Szekely, 2005). In many cases, disaster practitioners have focused largely on warning-response-relief approaches where technological advances in climate monitoring and short-term forecasting are linked to effective dissemination of climate hazard information and responses that at least save lives (Thomalla, 2006; Basher, 2009). Most disaster risk management planning currently aims to reduce disaster risks from existing climate hazards and vulnerabilities, sometimes little appreciating that the future may not be a repetition of the past hazards and risks (Dilley, 2005, Prabhaker et al, 2009). Yet, challenges remain in projecting future risks.

How can adaptation measures realize societal benefits now, and over coming decades, despite uncertainty about climate variability and change? Because future climate vulnerabilities and risks may change in unexpected directions, a range or ensembles of future climate change scenarios, and socio-economic scenarios along with impact models are needed to estimate the changing risks (UNFCCC, 2008; Prabhakar et al. 2009; Jones and Mearns, 2005; IPCC, 2007). However, this climate change scenario information is often not mainstreamed into adaptation planning (Wilby and Dessai, 2010; Wilby et al, 2009). This may be due to limitations to the availability of current climate hazards and risk information, a mismatch between climate model scales and the information needs of adaptation planners, access to dependable high-resolution regional climate change projections, a shortage of good quality climate data and methodologies for downscaling to decision-making scales, uncertainties in the climate scenarios themselves, the availability of relevant climate parameters from existing models and a shortage of information to guide understanding on the contribution that climate hazards make to risks, (Prabhakar et al, 2009; Basher, 2009; Wilby, 2009). Alternatives to these "top-down" or "scenario-led" approaches to adaptation are the 'bottom-up' methods that focus on reducing vulnerability to past and present climate variability and consider existing trends (Wilby and Dessai, 2010). These approaches include regular revisions of hazard and vulnerability assessments, use of redundancies, flexible planning and use of "precautionary" principles in policies and plans to deal with an increasingly uncertain and risky future climate (Dilley 2006; Auld, 2008b; Prabhakar et al, 2009; Baker, 2005; Wilby and Dessai, 2010 and see Section 6.4.2). While many developed countries are equipped to meet this challenge with national climate and socio-economic monitoring, climate models and analyses, redundancies and risk assessments, the situation is much less satisfactory in developing countries (Basher, 2009).

6.3.1.3. Developing Sector-Based Risk Management and Adaptation Approaches

National planning and policies are challenged in managing short-term climate variability while also ensuring different sectors and systems remain resilient and adaptable to changing extremes and risks over the long term (ISDR, 2007; Füssel, 2007; Wilby and Dessai, 2010). This challenge is to find the balance between the short-term "no regrets" actions to reduce immediate impacts with the longer-term actions needed to resolve underlying causes of vulnerability and to understand the nature of changing climate hazards (UNFCCC, 2008; OECD, 2009). "No regrets" policies and plans will continue to be important at the national scale and include funding, support to communities and local governments, declaring of disasters and seeking and coordinating international assistance when national capacity is overwhelmed (ISDR 2009; Sullivan et al 2009; Pande and Pande 2007). Longer term policies and plans include measures for the protection of ecosystem-based disaster-proofing services, built environment codes and standards that incorporate changing climatic design values, vulnerability assessments, zoning and land use management, preventive health care, alternative financial arrangement and public education (IPCC, 2007; Guzman, 2003; Prabhakar et al, 2009).

Achieving disaster risk reduction and climate change adaptation, while attaining human development goals requires a number of cross-cutting, inter-linked sectoral and development activities (Few et al, 2006; Thomalla et al, 2006). Linking risk reduction and adaptation policies and plans will require effective strategies within sectors as well as coordination between sectors. Climate change is far too big a challenge for any single ministry of a national government to undertake due to the coordination required among multiple sectors (CCCD 2009).

Table 6-1 provides examples of climate change adaptation and disaster risk management options that have been documented for sectors at the national scale, including governments, agencies and the private sector. These national level sectors and landscapes include: natural ecosystem management, agriculture and food security, fisheries, forestry, coastal zone management, water management, health, infrastructure including housing, cities and transportation, and energy. The sectoral risk reduction and adaptation options in the table are treated as a continuum of potential actions. How a particular policy and planning option fits in the continuum depends on the uncertainty of the climate risk, the capacity and willingness of the sector or country to act and the consequences and the timeframe needed to address the changing risks. As described in Section 6.3.1.1, these sectoral risk management and adaptation options are incremental and reinforce each other. For example, a specific option that deals with future climate risks in a sector will also need to consider the no and low regrets actions that deal with the current climate and uncertainties for the future climate (e.g. option 3 includes corresponding options under categories 1 and 2). The risk management and adaptation options for sectors at the national level can be categorized in the continuum and Table 6-1 as follows:

1) Climate proofing or "no regrets" plans and policies to reduce existing climate risks
2) Plans and policies that prepare for the uncertainties associated with the future climate
3) Climate change adaptation plans and policies that reduce disaster risks from future climate change
4) Plans and policies to transfer or "spread" the risks due to current and future hazards
5) Plans and policies to accept and deal with residual risks (e.g. can't adapt, unavoidable risks)
6) "Triple-win" plans and policies offering synergistic solutions for GHG reductions, climate change adaptation, disaster risk reduction and human development

[INSERT TABLE 6-1 HERE:
Table 6-1: National policies, plans, and programs: selection of disaster risk management and adaptation options.]

Several of the national level sectoral risk management and adaptation options outlined in Table 6-1 are described in the Chapter 9 case studies. These cases illustrate some of the realities and challenges that face developing, and developed countries in dealing with risk management and adaptation as well as the benefits and opportunities that can emerge, often at reasonable costs (see Section 9.1.1). In the majority of the Chapter 9 case studies, the starting point for risk management and adaptation are the options that address existing vulnerabilities to climate variability and extremes. For example, the case studies for cyclones, heat waves, floods, droughts and cities and settlements illustrate realized benefits from implementing "no regrets" all hazards Early Warning Systems, improved weather and climate predictions, better data collection and public education on hazards and response actions— irrespective of whether the country is developing and developed (see Chapter 9). The Bangadesh cylone case study, in particular, proves conclusively that (coastal) volunteer networks offer an effective mechanism for dissemination of warnings that allow time-critical responses on the ground and safe evacuation of vulnerable populations to cyclone shelters (see Chapter 9 case study 18). Many of the Chapter 9 case studies, including those for cyclones, heat waves, drought, sandstorms, floods and epidemics, demonstrate that preventative “no regrets” actions in the form of education campaigns, increased awareness of risks at the community level and the engagement of communities in emergency response and prevention actions are achievable and do provide significant payoffs at reasonable costs. The Chapter 9 case studies for cyclone, cities, coastal and SIDS further demonstrate the success of some developing countries in providing safe and climate-proof temporary infrastructure to their vulnerable populations, often as emergency refuges in the form of shelters, killas (raised earthen platforms for animals), or through reinforced sections of housing and upgraded building codes containing updated climatic design values (see Chapter 9.x.x case studies).

A theme threading through many of the case studies and evident in almost all of the sectoral options in Table 6-1 is the benefit that a combination of hard and “soft” engineering or Ecosystem-based Adaptation (EbA) solutions offers in building resilient communities. EbA, integrated water and coastal resource management and land use management approaches all recognize that the natural environment and ecosystems need to be conserved and protected or restored in order to provide critical ecosystem services to reduce climate vulnerabilities for sectors and national economies. For example, the Chapter 9 case studies for sandstorm, flood, drought, cyclones, epidemics and heat wave events provide practical illustrations of beneficial EbA, water and land use practices that have been proven to work in reducing disaster risks (see Chapter 9, case study 9.x.x). The cases also illustrate the realities and significant challenges inherent in developing and implementing national scale risk management and climate change adaptation options, including lack of climate and weather data, lack of institutions and systems to effectively disseminate weather warnings and to efficiently respond to them, insufficient finances, imbalances in funding spent on disaster relief and reconstruction compared to risk reduction, institutional fragmentation and other barriers to the assignment of responsibilities for appropriate disaster and preventative responses.

The case studies in Chapter 9 also highlight a real shortage of examples where risk reduction and adaptation options have been implemented for future climate change risks and uncertainties. In the Arctic, SIDS and coastal regions case studies where climate change impacts are already a reality, some adaptation options are being considered and implemented (e.g. national standards and guidelines for foundations in Canadian permafrost zones) but many more adaptation solutions are needed (NRTEE, 2009; CSA, 2010; also see Chapter 9, case study 9.x.x). Overall, dealing with future climate change risks will require more flexibility to accommodate changes in the frequency and magnitude of extreme impacts over time as well as a continuous re-evaluation of risks and re-adjustment of risk management and adaptation plans and policies (Sperling and Szerkely, 2005; IPCC, 2007). Climate change will mean that further precautions and more preventative adaptation options will be needed. For example, in some cases involving hard engineering, it may mean a need to increase safety factors to ensure that infrastructure can withstand future increases in critical thresholds for extremes, such as peak winds and extreme rainfalls (Auld, 2008a; Sperling and Szerkely, 2005; World Bank, 2008b; World Water Council, 2009).

6.3.2. Strategies including Legislation, Institutions, and Finance

National systems for managing the risks of extreme events and disasters are shaped by legislative provision and associated compliance mechanisms, the approach to co-ordinating actors in cross sectoral, cross stakeholder bodies and financial and budgetary processes that allocate resources to actors working at different scales. These elements tend to form the ‘technical infrastructure’ of national systems, but there are also other non-technical dimensions of ‘good governance’, such as the distribution and decentralisation of power and resources, structures and processes for decision-making, equity, transparency and accountability, and participation of a wide range of stakeholders groups (UNDP 2004a). Together these elements form the subject of this section, which is divided into three subsections: (a) legislation and compliance mechanisms, (b) organisational arrangements and distribution of responsibilities across scales, (c) finance and budget allocation. At the start of this section, it is important to recognise the variation between countries in governance capacity for managing the risks and uncertainties of changing climate extremes also cuts across this section. This recognition is based on the understanding that risks and uncertainties are addressed through both formal and informal governance modes and institutions in all countries (Jaspars and Maxwell 2009), but the balance between the two can be remarkably different across countries depending on the specific economic, political or environmental context of the individual country or the scale at which action is taking place (cf. Menkhaus, 2007; Kelman, 2008).

6.3.2.1. Legislation and Compliance Mechanisms

Legislation that supports disaster risk management by establishing organisations and their mandates, clarifies budgets, provides (dis)incentives and develops compliance and accountability mechanisms is an important component of a national disaster risk management system (UNISDR HFA 2005, UNDP 2004). Legislation creates the legal context of the enabling environment in which others, working at national and sub-national scales, can act and it can help define people's rights to protection from disasters, assistance and compensation (Pelling and Holloway 2006). With new information on the impacts of climate change, legislation on managing disaster risk may need to be modified and strengthened to reflect changing rights and responsibilities and to support the uptake of no, low, medium and high regrets adaptation options (UNDP 2004; see Chapter 9 case study on 'effective legislation for adaptation and disaster risk reduction). 'National Platforms' for managing disaster risk, the multi-stakeholder, cross sectoral co-ordination bodies supported by the Hyogo Framework for Action, are seen as key advocates for new and improved legislation (ISDR 2007), but regional disaster management bodies, such as in the Caribbean or the Pacific region, can also be influential at national level where national co-ordinating bodies lack capacity or are missing (Pelling and Holloway 2006).

While the large majority of countries (in excess of 80%) have some form of disaster management legislation (UN-ISDR 2005), little is known about what proportion of legislation is oriented toward managing uncertainty and reducing disaster risk compared with disaster response, whether legislation includes provision for the impact of climate change on disaster risk and whether aspects of managing disaster risk are included in other complimentary pieces of legislation (see Chapter 9 case study). However, where reforms of disaster management legislation have occurred, they have tended to: (a) demonstrate a transition from emergency response to a broader treatment of managing disaster risk, (b) recognise that protecting people from disaster risk is at least partly the responsibility of governments, (c) promote the view that reducing disaster risk is everyone's responsibility (see case study in Chapter 9). For example, Viet Nam has taken steps to integrate disaster risk management into legislation across key development sectors –its Land Use Law and Law on Forest Protection. Viet Nam's Poverty Reduction Strategy Paper also included a commitment to reduce by 50% those falling back into poverty as a result of disasters and other risks (Pelling and Hollway 2006; Viet Nam National Report on Disaster Reduction 2005). The Chapter 9 case study highlights a number of components of effective disaster risk management legislation. An act needs to be: (a) comprehensive and overarching act, (b) establish management structures and secure links with development processes at different scales and (c) establish participation and accountability mechanisms that are based on information provision and effective public awareness and education. Chapter 9 includes detailed case studies from legislation development processes in the Philippines and South Africa. Box 6-1 supplements these cases with reflections on the process that led to the creation of disaster risk management legislation in Indonesia.

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Box 6-1. Enabling Disaster Risk Management Legislation in Indonesia

Indonesia: Disaster Management Law (24/2007)
The legislative reform process in Indonesia that resulted in the passing of the 2007 Disaster Management Law (24/2007) created a stronger association between disaster risk management and development planning processes. The process was successful because of the following elements:

- **Strong, visible professional networks -** Professional networks born out of previous disasters meant a high level of trust and willingness to co-ordinate became pillars of the legal reform process. The political and intellectual capital in these networks, along with leadership from the MPBI (The Indonesian Society for Disaster Management) was instrumental in convincing the law makers about the importance of disaster management reform.
- **Civil Society Leading the Advocacy -** Civil society led the advocacy for reform has resulted in CSOs being recognised by the Law as key actors in implementing disaster risk management in Indonesia

- The impact of the 2004 South Asian tsunami helping to create a conducive **political environment -** The reform process was initiated in the aftermath of the tsunami which highlighted major deficiencies in disaster management. However, the direction of the reform (from emergency management towards DRR) was influenced by the international focus, through the HFA, on DRR.
- An **Inclusive Drafting Process -** Consultations on the new Disaster Management Law were inclusive of practitioners and civil society, but were not so far-reaching as to delay or lose focus on the timetable for reform.
- Consensus that **passing an imperfect law is better than no law at all** - An imperfect law can be supplemented by additional regulations, which helps to maintain interest and focus.

Source: United Nations Development (2009); UNDP (2004a); Pelling and Holloway (2006)

_____ END BOX 6-1 HERE _____

Where risk management dimensions are a feature of national legislation positive changes are not always guaranteed (UNDP 2004a). A lack of financial, human or technical resources and capacity constraints present significant obstacles to full implementation (ISDR 2005 *review of national submissions*), especially as experience suggests legislation must be implemented continuously from national to local level and is contingent on strong monitoring and enforcement frameworks (UNDP 2004a) and adequate decentralisation of responsibilities and human and financial resources at every scale (Pelling and Holloway 2006). There is anecdotal evidence of disaster risk management legislation that is technically excellent but practically unenforceable (UNDP 2004a). Building codes for instance are often not implemented because of a lack of technical capacity and political will of officials concerned. Where enforcement is unfeasible, accountability for disaster risk management actions is impossible – this supports the need for an inclusive, consultative process for discussing and drafting the legislation (UNDP 2007). ‘Effective’ legislation also includes benchmarks for action, a procedure for evaluating actions, joined-up planning to assist co-ordination across geographical or sectoral areas of responsibility and a feedback system to monitor risk reduction activities and their outcomes (ISDR 2005, Pelling and Holloway 2006).

Improving risk management legislation in the context of climate change likely means stronger synergy with land-use planning and environmental protection laws, and the integration of environmental management principles into existing legislation (UN-ISDR 2007, GAR 2009). However, the limited political power of risk management actors in many governments limits the ability to affect change alone across other areas of legislations and reform will likely require cross-sectoral coalitions. Evidence from the Philippines cited in Chapter 9, the first country to enact legislation that explicitly attempts to integration climate change and disaster risk management dimensions across scales, highlights the importance given to ensuring co-ordination across all levels of government, provision of financial resources for implementation across scales and a commitment to regularly assess the impact of climate change on disaster risks and extremes.

6.3.2.2. Coordinating Mechanisms and Linking Across Scales

Given that the task of managing the risks of climate extremes and disasters cuts across the majority of development sectors and involves multiple actors, multi-sectoral and multi-stakeholder mechanisms are commonly cited as preferred way to ‘organise’ disaster risk management systems at national level. The Hyogo Framework for Action (HFA) terms these mechanisms *National Platforms*, which are defined by the HFA (footnote 10) as ‘a generic term for national mechanisms for co-ordination and policy guidance on disaster risk reduction (DRR) that are multi-sectoral and inter-disciplinary in nature, with public, private and civil society participation involving all concerned entities within a country’. National Platforms were first supported by a resolution of the UN General Assembly in 1999 (UNGA 1999/63) and more recently reaffirmed in A/RES/62/192. Guidelines on establishing National Platforms suggest that they need to be built on existing relevant systems and should include participation from different levels of government, key line ministries, disaster management authorities, scientific and academic institutions, civil society, the Red Cross/Red Crescent, the private sector, opinion shapers and other relevant sectors associated with disaster risk management (ISDR 2007). With no formal evaluation of National Platform, there is little evidence to suggest whether or not such multi-sectoral co-ordination mechanisms lead to more effective disaster risk management.

Many national climate change adaptation co-ordination mechanisms remain are largely disconnected from such disaster risk management platforms though joint bodies are beginning to emerge [UN-ISDR GAR 2009], despite calls to involve climate change focal points/organisations into National Platforms (ISDR 2007). Benefits of improved co-ordination between climate adaptation and disaster risk management bodies, and development and disaster management agencies include the ability to (i) explore common trade-offs between present and future action, including addressing human development issues and reducing sensitivity to disasters versus addressing post disaster vulnerability ; (ii) identify synergies to make best use of available funds for short-to longer term adaptation to climate risks as well as to tap into additional funding sources, (iii) share human, information, technical and practice resources, (iv) make best use of past and present experience to address emerging risks, (v) avoid duplication of project activities; and (vi) collaborate on reporting requirements (Mitchell and Van Aalst 2008). Barriers to integrating disaster risk management and adaptation co-ordination mechanisms include the underdevelopment of the 'preventative' component of disaster risk management, the fragmentation of projects that integrate climate change in the context of disaster risk management, disconnects between different levels of government and the weakness of both disaster risk management and climate change adaptation in national planning and budgetary processes (Few *et al.*, 2006; Mitchell and Van Aalst 2008).

While national level co-ordination is important and the majority of risks associated with disasters and climate extremes are owned by national governments and are managed centrally; a broad range of research reflects that decentralization is critical to effective risk management, especially in supporting community-based disaster risk management processes. Whereas, other literature suggests that decentralisation as not always been successful in achieving improved disaster risk management outcomes, on the contrary, on some occasions it has been utilized in inappropriate ways, for example by delegating responsibilities to local governments when these are not prepared to do so because they do not have the skills or finances required, and neither the jurisdiction or political power (Twigg, 2004). It is important to take into account that decentralization is not only based on governance systems supported by policy and legislation, but also in allocation of time, resources and in building trust (Tompkins *et al.*, 2008). Therefore, a tension exists between devolution or centralization of disaster risk management. While on the one hand centralization is necessary to overcome compartmentalization (Wisner 2003), ad hoc decision-making, and the concretization of localized power relations (Naess et al. 2004), devolution is critical because it results in more accountable, credible, and democratic decision-making. These decisions about governance approaches are critical because they shape efficiency, effectiveness, equity, and legitimacy of responses (Adger et al. 2003). In addition, motivation for management at a particular scale promises to influence how well the impacts of disasters and climate change are managed, and therefore affect disaster outcomes (Tsing et al., 1999). Finally, decisions made at one scale may have unintended consequences for another (Brooks and Adger 2005), meaning that governance decisions will have ramifications across scale and contexts. In all cases, the selection of a framework for governance of disasters and climate change related risks may be issue or context-specific (Sabatier 1986).

Current management practices have tended to be centralized at the federal/national level. This may be, in part, due to the ways in which many disasters and climate extremes affect environmental systems that cross political boundaries resulting in scale discordance if solely locally managed (Cash and Moser 1999), or because human reactions cross local boundaries, such as migration in response to disasters, necessitating national planning (Luterbacher 2004). In addition, in situations where civil society is flattened due to poverty, marginalization, or historical political repression, regional and federal governments with access to resources may be most important in instigating public action (Thomalla et al. 2006). National-level policies can facilitate otherwise impossible localized strategies through the establishment of resources or legal frameworks (Adger 2001) and often shape what localities can accomplish within existing governance frameworks (Keskitalo 2009).

Yet, centralized approaches have faced many challenges. Disaster preparedness in least developed countries, which has often been centralized and focused on a particular risk rather than a holistic approach, has been unable to advance capacity at the grassroots level (O'Brien et al. 2006). For example, national adaptation efforts in Southern Africa have been insufficiently integrated into local strategies, resulting in resilience gaps (Stringer et al. 2009). Challenges regarding credibility, stability, accountability, and inclusiveness are some of the critical issues that plague efforts at the national level (Bierman 2006). The private sector has begun to engage in financial assistance for climate change impacts through insurance for developing nations that have limited supplies to assist impacted households (Hoeppe and Gurenko 2006). However, it is not yet clear how effectively such funding can be distributed to households themselves. Devolution of management is supported by the need to overcome these challenges.

As a general rule, actions generated within and managed by communities are most effective since they are context-specific and tailored to local environments (Cutter 2003; Liso et al. 2003; Mortimer and Adams 2001). Bottom-up management of climate and disaster risks acknowledges that the vulnerable live within countries, and are not nations themselves (Kate 2000). Involvement of local or grassroots groups in the planning and implementation of preparedness plans can lead to greater resilience (Larsen and Gunnarsson-Östling 2009). For example, communities themselves can lead vulnerability assessments as a part of community-based adaptation (Yamin et al. 2005). Communities can also be effectively engaged in information dissemination and training, awareness raising, accessing local knowledge or resources, and mobilizing local people (Allen (2006). Local management may need assistance from non-traditional sources. The private sector can facilitate action through the provision of resources, technology, and tools, such as insurance against the extreme impacts of climate change to support (Linnerooth-Bayer et al. 2005). Such programs could introduce preventive measures, such as retrofitting buildings and public education.

Since environmental systems relate to risks for local population and since environmental management functions across scales (Berkes 2002), the creation of effective multi-level governance within national systems for managing risk that span these scales are critical in responses to climate change and changing disaster risks (Adger et al. 2005; Olsson and Fulke 2001). Devolution of activities for climate-related disaster risk reduction can also be managed by cities that develop plans for multiple communities, such as that in Dhaka, Bangladesh where urban-level plans have advanced community resilience (Roy 2009). Such city-level plans can be communalized through the incorporation of participatory approaches (Laukkonen 2009). When necessary, localized plans should be supported by the integration of multiple levels of management, although questions about how to scale up from localized assessments to national-level plans still remain (van Aalst et al. 2008). Dryland communities in Chile have created local committees to manage extreme events when national and regional level institutions did not effectively communicate or collaborate with them (Young et al. 2010). The Cayman Islands responses to Hurricane Ivan in 2004 after three prior events, Gilbert, Mitch, and 2000 Michelle, demonstrated that adaptation planning at community and national levels was necessary to improve preparedness and resilience (Adger et al. 2005). These measures included improving localized social cohesion and diversifying adaptation strategies (Tompkins 2005). Procedural dimensions, such as participatory models, that allow for involvement for a wider range of local stakeholders provide a mechanism to mitigate existing power dynamics that might otherwise be concretized in localized planning (Paavola and Adger 2002). If multiple levels of planning are to be implemented, such mechanisms for facilitation and guidance on the local level is needed in order that procedural justice is guaranteed during the implementation of national policies (Thomas and Twyman 2005). Taking these ideas into account might allow national governments to help facilitate programs where local community members jointly engage in risk management (Perez et al.1999). Such programs may allow for an integration of bottom-up and top-down approaches that overcomes each approaches strengths and weaknesses (Urwin and Jordan 2008).

6.3.2.3. Finance and Budget Allocation

Governments in the past have ignored catastrophic risks in decision-making, implicitly or explicitly exhibiting risk-neutrality (Guy Carpenter, 2000). This is consistent with the Arrow Lind theorem (Arrow and Lind 1970), according to which a government may efficiently (i) pool risks as it possesses a large number of independent assets and infrastructure so that aggregate risk becomes negligible, and/or (ii) spread risk across the population base, so that per-capita risk to risk-averse household is negligible. Governments, because of their ability to spread and diversify risks, are considered to "the most effective insurance instrument of society" (Priest 1996). It has been argued that, although individuals are risk-averse [to natural disasters risk], governments should take a risk-neutral stance. The reality of developing countries suggests otherwise and the above does do completely apply to developing countries, forcing a recent paradigm shift and critical reevaluation of governments taking ‘risk neutral’ approach to managing risks. Government decisions should be based on the opportunity costs to society of the resources invested in the project and on the loss of economic assets, functions and products. In view of the responsibility vested in the public sector for the administration of scarce resources, and considering issues such as fiscal debt, trade balances, income distribution, and a wide range of other economic and social, and political concerns, governments should not act risk-neutral (OAS, 1991).

Many highly exposed developing countries have a precarious economic base, are faced with shallow and exhausted tax bases, high levels of indebtedness and the inability to raise sufficient and timely capital to replace or repair damaged assets and restore livelihoods following major disasters, exacerbating the impacts of disaster shocks on poverty and development (OAS, 1991; Mechler, 2004; Bayer, Pflug and Mechler, 2005; Hochrainer, 2006; Ghesquiere and Mahul, 2007; Cummins and Mahul, 2008). Exposed countries often also rely on donors to “bail” them out after events, which can be described as an instance of *moral hazard*, although ex–post assistance usually only provides partial relief and reconstruction funding, and such assistance is also often associated with substantial time lags (Pollner, 2001; Mechler, 2004). Consequently, a risk neutral stance in dealing with catastrophic risks may not be suitable for exposed developing countries with little diversified economies or small tax bases. Accordingly, assessing and managing risks over the whole spectrum of probabilities is gaining momentum (Cardenas, 2007; Cummins and Mahul, 2008).

Also, in more developed economies less pronounced but still important effects have been identified. For example, disasters pose significant contingent liabilities for governments and prudent planning is necessary to avoid debilitating consequences (Mechler et al. 2010). This is shown by the Austrian political and fiscal crisis in the aftermath of large scale flooding that led to losses in billions of Euro in 2002. Climate change, projected to increase the disaster burden, adds additional impetus for planning for and reducing disasters risks. Given the uncertainties associated with climate change and extreme events, development planning for reducing risks will need to be based on a systematic estimate of risk.

Budget and resource planning for extremes is not an easy proposition. Governments commonly plan and budget for *direct* liabilities, that is liabilities that manifest themselves as certain and annually recurrent events. Those liabilities can be of explicit nature (as recognized by law or contract), or implicit (a moral obligation) (see Table 6-2). In turn, governments are not good at planning for contingencies, that is, obligations for probable events, which is where climate extremes and adaptation fall into. Explicit, contingent liabilities have to do with the reconstruction of infrastructure destroyed by events, implicit ones with providing relief which generally throughout the globe is a recognized moral liability, albeit serviced to varying degrees (Schick and Brixi, 2004). In many particularly developing countries, government do not even explicitly plan for contingent liabilities, and rely on reallocating their resources following disasters, raise capital from domestic and international donations to meet infrastructure reconstruction costs.

[INSERT TABLE 6-2 HERE:
Table 6-2: Government liabilities and disaster risk.]

Rather than planning for or having contingency funds available post-disaster, countries also have tended to rely on development partner support. Knowing that such additional funds are usually forthcoming, it creates a serious moral hazard problem (see World Bank 2006 b). More recently, some developing countries that face large contingent liabilities in the aftermath of extreme events and associated financial gaps have begun to plan for contingent natural events. Countries such as Mexico, Colombia and many Caribbean countries now include contingent liabilities into their budgetary process and eventually even transfer their risks (Cardenas et al., 2007; Cummins and Mahul, 2008; Linnerooth-Bayer and Mechler, 2008; see Box 6-2). Similarly, many countries have started to also focus on improving human development conditions as an adaptation strategy for climate change and extreme events, particularly with the help of international agencies such as the World Bank. These deliberations are in line with the described *no* and *low regrets* strategies discussed in 6.3.1.1.

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Box 6-2. Case Study: Mexico's Fund for Natural Disasters, FONDEN

Mexico lies within one of the world's most active seismic regions and in the path of hurricanes and tropical storms originating in the Caribbean Sea, Atlantic and Pacific Oceans. Mexico's population and economy is highly exposed to natural hazards and in the past severe disasters have created large fiscal liabilities and imbalances.

Given its high financial vulnerability, the Mexican Government passed a law in 1994 requiring federal, state and municipal public assets to be insured relieves the central government of having to pay for the reconstruction of public infrastructure, although the proper level of insurance particularly for very large events remains a concern (World Bank, 2000). In 1996 the national government established a system of allocating resources into FONDEN (Fund For Natural Disasters) to enhance the country's financial preparedness for natural disaster losses. FONDEN provides last-resort funding for uninsurable losses, such as emergency response and disaster relief. In addition to the budgetary program, in 1999 a reserve trust fund was created, which is filled by the surplus of the previous year's FONDEN budget item. FONDEN's objective is to prevent imbalances in the federal government finances derived from outlays caused by natural catastrophes.

The FONDEN program started well, although in recent years some concerns have been raised, particularly due to regular demands on the funds. Budgeted FONDEN resources have been declining in the last few years, demands on FONDEN's resources are becoming more volatile, and outlays have often exceeded budgeted funds, causing the reserve fund to decline. In 2005, after the severe hurricane season affecting large parts of coastal Mexico, the fund was finally exhausted. This has forced the Mexican Government to look at alternative insurance strategies, including hedging against natural disaster shocks, and government agencies at all levels providing their insurance protection independent of FONDEN, and the instrument should indemnify only losses that exceed the financial capacity of the federal, local or municipal government agencies. In 2006 Mexico became the first transition country to transfer part of its public sector natural catastrophe risk to the international reinsurance and capital markets, and in 2009 the transaction was renewed for another three years covering both hurricane and earthquake risk.

Source: based on Cardenas *et al.* 2007

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6.3.3. Practices including Methods and Tools

Governments, and other agencies working in the national system have developed a set of good, and not so good, practices for managing disaster risk. Practices involving risk assessment, hard and soft management options, risk transfer, public awareness and early warning are all raised in this sub-section, which is divided into those practices associated with building a culture of safety (6.3.3.1), risk reduction (6.3.3.2), risk sharing and transfer (6.3.3.3) and managing the impacts (6.3.3.4).

6.3.3.1. Building a Culture of Safety

Building a culture of safety involves assessing risks, providing and communicating reliable and adequate information to serve as the basis for planning interventions as well as generally raising public awareness of risks.

6.3.3.1.1. Assessing risks and maintaining information systems

The first key step in managing risk is to assess and characterise risk. In terms of risk drivers, disaster risk commonly is defined by three factors: the hazard, exposure of elements, and vulnerability (Swiss Re, 2000; Kuzak, 2004; Grossi and Kunreuther, 2005). Thus, understanding risk involves observing and recording impacts, hazard analysis, studying exposure and vulnerability assessment. Responding to risks is dependent on the way risk-based information framed in the context of public perception and management needs (See Chapter 5). The technical aspects of risk may be characterized in terms of deterministic and probabilistic assessments of their likelihood (see Box 6-3).

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Box 6-3. Deterministic and Probabilistic Risk Assessment

Two distinct approaches have been used to assess risks and what actions to take – a deterministic assessment of extremes focussing on certain *design events* such as a 100 year event and probabilistic risk assessments taking the whole probability distribution of events into account (see Freeman et al., 2001; Apel et al., 2004; Mechler, 2004; World Bank, 2004; Hall, Sayers and Dawson, 2005; Cardona et al., 2007; Hochrainer, 2006; Feyen, Barredo and Dankers, 2009; Mechler et al., 2010). Although difficult and sometimes not feasible, a probabilistic approach is to preferred. In terms of outcomes, disaster risk is commonly defined as the probability of potential impacts affecting people, assets or the environment (Smith, 1996), thus ideally, probabilistic information is generated framing risk in terms of loss exceedance curves indicating the probability of losses such as for a 50 , 100, 200 year event. While they are complex and require some technical expertise, probabilistic approaches are well suited to inform key decisions and represent uncertainty, which is particularly important when considering catastrophic events with potentially large impacts but small probabilities of occurrence. Deterministic approaches on the other hand ignore the presence of aleatoric (natural) uncertainty and provide only partial information.

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National governments have a fundamental role in providing good quality and context-specific risk information about, for example, the geographical distribution of people, assets, hazards, risks and disaster impacts and vulnerability to support disaster risk management (McBean, 2008). Good baseline information and robust time series information are key for long-term risk monitoring and assessments, not only for hazards but also for evaluating the evolution of vulnerability and exposure (McEntire and Myers, 2004; Aldunce and León, 2007). Regular updating of information about hazards, exposure and vulnerability is recommended because of the risk dynamics, especially today due to the affects of climate change on disaster risk and the associated uncertainty this creates (ISDR, 2004; Prabhakar, 2008). Considerable progress has been made in the use of information (ISDR, 2009). Nevertheless, in many countries this is not a regular practice and efforts to document impacts are started only after major disasters (ISDR, 2004; Prabhakar, 2008). Table 6-3 shows a sample of the kinds of information required for effective disaster risk management and climate change adaptation activities.

[INSERT TABLE 6-3 HERE:
Table 6-3. Information requirements for selected disaster risk reduction and climate change adaptation activities.]

As to impacts and losses, country and context specific information, including baseline data about observations (different types of losses, weather data) from past events, are often very limited and of mixed quality (see Carter et al., 2007; Embrechts et al., 1997). Data records at best may date back several decades, and thus often would provide only one reference data point for extreme events, such as a 100 year event. Data on losses from extremes can also be systematically biased due to high media attention or unusual donor support (Sapir and Below, 2002). At times the data on losses are incomplete, as in the Pacific SIDS, because of limited capacity to systematically collect information at the time of disaster, or because of inconsistent methodologies and the costs of measures used (Chung 2009, Lal et al 2009).

Comparisons of disaster loss databases have shown significant variations in documented losses due to inconsistencies in the definition of key parameters and estimation methods used (eg Chung 2009, Lal 2010), emphasising the need to standardise parameter definitions and estimation methods (Guha-Sapir and Below, 2002 ; Tschoegl et al., 2006). For some countries, reasonable quality and quantity of information may exist on the direct impacts particularly where the reinsurance industry, consulting firms and multi-lateral financial institutions have worked together with the research communities. Limited information is generally available on socially relevant effects, such as the incidence of health effects post disaster as well ecosystem impacts, which have not been well studied (Benson and Twigg 2005). Furthermore, the assessment of indirect and flow-on economic effects of disasters, such as on income generating sectors, and national savings needs greater attention, and can often be very useful to assess risks later on, using statistical estimation techniques (Embrechts et al. 1999), or catastrophe modeling approaches (Grossi and Kunreuther, 2005).

As to addressing the different components of risk, hazard analysis involves determining the nature of hazard(s) affecting a certain area with specific intensity, duration, and frequency in order to derive a stochastic representation of the hazard. Climate change, shown to already affect extreme weather-related events in frequency and severity (IPCC, 2007, Solomon et al., 2007), needs to be first and foremost factored into such an analysis. Climate models have been assessed and currently are not good at reproducing spatially explicit climate extremes due to limited data and inadequate (coarse) resolution (Goodess et al., 2003). Hence, projections of extreme events for future climate are highly uncertain and often are important hindrances to robustly projecting sudden onset of risk, such as flood risk, while drought risks, which are slower onset phenomena more strongly characterised by boundary conditions, can better be projected on average (Christensen and Christensen, 2002; Kundzewicz et al., 2006). The severity and duration of drought and it's occurrence in combination with increasing aridity are not well understood. When projecting risks into a future it is important to address the non-stationarity exhibited by the system in order not to underestimate the risk (Milly et al., 2008). Although there have been several articles criticizing the assumption of stationarity, it is not apparent what alternative methods should be used. However failure to account for changes in baseline conditions may lead to the following consequences: (i) early warnings may become unreliable and therefore will lose the trust enjoyed by the stakeholders at risk (Oloruntoba, 2005), (ii) risk management strategies may become inefficient and obsolete as strategies are based on past risk not adequately reflecting expected future changes (Pflug and Römisch, 2007); (iii) natural resource management policies may not appropriately refer to newly hazard prone areas, and therefore the number of those exposed to hazards may increase (Vari and Ferencz, 2007).

Apart from the climate change component, vulnerability and exposure will also change over time, and these aspects of the risk triangle are often not considered equally (see Hochrainer and Mechler, 2010). A key component in the risk assessment process is to determine the exposed elements at risk. This may relate to persons, buildings structures, infrastructure (e.g. water and sewer facilities, roads and bridges) or agricultural assets in harm's way, which can be impacted in case of a disaster event (ADPC 2000; World Bank, 2004), and for national level assessments their aggregate values are of interest. Ideally, this would be based on national asset inventories, national population census, and other national information.. In practice, collecting an inventory on assets and their values often proves very difficult and expensive due to the heterogeneity and sheer number of the examined elements (see Cummins and Mahul, 2007).

The third building block of risk, vulnerability, refers to the susceptibility of the exposed elements to incur damages and follow on impacts (ADPC, 2000; UNISDR, 2008). For managing risk, vulnerability is a key component, yet it is the most elusive of three drivers of risks due to a lack of standardized definitions. The challenge in assessing vulnerability is to build on the rigour of (more narrowly focussed) risk assessments and contribute to the complex scientific, institutional, and policy processes necessary for effectively assessing and reducing vulnerability to climate change (Birkmann, 2006).

6.3.3.1.2. Promoting public awareness, including education and early warning systems

National governments create the environment and communication channels to develop and disseminate different kinds of information, for example about hazards that affect different populations. For this, a robust and up-to date Early Warning Systems (EWS) is critical to not only mitigate the impacts of disasters, but to also provide timely warning to the agencies involved in managing the risks of climate extremes and disasters and to the affected population for quick response (White et al., 2004; Aldunce and Neri, 2008; McBean, 2008). Early warning systems have been interpreted narrowly as technological instruments for detecting and forecasting impending hazard events and for issuing alerts (NIDIS, 2007). This interpretation, however, does not clarify whether warning information is actually used to reduce risks (UNISDR, 200; NIDIS 2007). Governments maintain early warning systems to warn their citizens and themselves about, for example, impending climate- and weather-related hazards. "Early warnings" of potentially poor seasons to inform key actions for agricultural planning have been successful in producing proactive responses. This is reliant on close inter-institutional collaboration between national meteorological and hydrological services and agencies that directly intervene in rural areas, such as extension services, development projects and civil society organisations (Hammer, 2000; Meinke et al., 2001).

An effective early warning system delivers accurate, timely, and meaningful information dependably and on time (ISDR, 2005; Auld, 2008; Basher, 2006; Wimbi, 2007). Warnings buy the time needed in advance of hazards to evacuate populations, reinforce infrastructure, reduce potential damages or prepare for emergency response (Auld, 2008). To be effective and complete, an early warning system needs to comprise four interacting elements (ISDR, 2006a; Basher, 2006): (i) generation of risk knowledge including montoring and forecasting, (ii) surveillance and warning services, (iii) dissemination and communication and (iv) response capability. The success of an early warning system depends on the extent to which the warnings trigger effective response measures (van Aalst, 2009; Wimbi, 2009). Warnings can and do fail in both developing and developed countries due to inaccurate weather and climate forecasting, public ignorance of prevailing conditions of vulnerability, failure to communicate the threat clearly or in time, lack of local organization and failure of the recipients to understand or believe in the warning or to take suitable action (ISDR, 2001; Auld, 2008). Warnings must be received and understood by a complex target audience and need to have a meaning that is shared between those who issue the forecasts and the decision-makers they are intended to inform (Auld, 2008; Basher, 2006; ISDR, 2006a). Because emergency responders and the public often are unable to translate the scientific information on forecast hazards in warnings into risk levels and responses, future work is needed that can identify general impacts, prioritize the most dangerous hazards, assess potential contributions from cumulative and sequential events to risks and identify thresholds linked to escalating risks for infrastructure, communities and disaster response (Auld, 2008; ISDR, 2006a).

Different hazards and different sectors often require unique preparedness, warnings and response strategies (ISDR, 2006a; Basher, 2006; van Aalst, 2009). Some may represent singular extreme events, sequences or combinations of hazards. The World Meteorological Organization (WMO), National Meteorological and Hydrological Services and UN partners recognize that combinations of weather and climate hazards can result in complex emergency response situations and are working to establish multi-hazard early warning systems for complex risks such as deadly heat waves and vector-borne diseases (WMO, 2007; ISDR, 2006a) and early warnings of locust swarms (WMO, 2007; WMO, 2004b). Some “creeping” hazards can evolve over a period of days to months; floods and droughts, for example, can result from cumulative or sequential multi-hazard events when accompanied by an inherent vulnerability (Auld, 2008; Basher, 2006).

Understanding by the public and community organizations of their risk and vulnerabilities are critical but insufficient for risk management requiring that early warning systems be complemented by preparedness programmes as well as land use and urban planning, public education and awareness programmes (ISDR, 2006a; Basher, 2006; Wimbi, 2007). Public awareness and support for disaster prevention and preparedness is often high immediately after a major disaster event—such moments can be capitalized on to strengthen and secure the sustainability of early warning systems (Basher, 2006). It should be noted that such “policy windows” are seldom used without the prexistence of a social basis for cooperation that in turn supports a collaborative framework between research and management. The timing and form of climatic information (including forecasts and projections), and access to trusted guidance to help interpret and implement the information and projections in decision-making processes may be more important to individual users than improved reliability and forecast skill (Pulwarty and Redmond,1997; Rayner et al., 2001).

Early warning information systems are multi-jurisdictional and multi-disciplinary, requiring anticipatory cooordination across a spectrum of technical and non-technical actors. National governments play critical roles in setting the high-level policies and supporting frameworks to facilitate multiple organizational and community networks that sustain early warning systems to issue national hazard warnings and identify and diffuse successful approaches (ISDR, 2006b, Pulwarty et al, 2004). National governments need to interact with regional and international governments and agencies to strengthen early warning capacities and to ensure that warnings and related responses are directed towards the most vulnerable populations (ISDR, 2006b). At the same time, national governments have a role in supporting regions and sub-national governments in developing operational and response capabilities (ISDR, 2006b; see 6.3.3.4).

6.3.3.2. Reducing Climate-Related Disaster Risk

Disaster risk reduction activities include a broad range of options that vary from safe infrastructure and building codes to those aimed to protect natural ecosystems, human development and, in extremes, humanitarian focused actions. These and other different options are addressed in the following sections noticing how risk reduction and disaster response measures are increasingly being considered as good practices to deal with uncertainty and climate change.

6.3.3.2.1. Applying technological and infrastructure-based approaches

The built environment of both developing and developed countries will be impacted significantly by climate change (Wilby, 2007; Auld, 2008a; Stevens, 2009). Climate change has the potential to impact the safety of existing infrastructure, increase the frequency of weather-related disasters, increase premature weathering regionally, change engineering and maintenance practices and to alter building codes and standards where they exist (Auld, 2008a). With potential increases in extreme events regionally, it is expected that small increases in climate extremes above regional thresholds will have the potential to bring large increases in damages to all forms of existing infrastructure (Auld, 2008a; Coleman, 2002; Munich Re, 2005).

The need to address the risk of climate extremes and disasters in the built environment and urban areas, particularly for low- and middle-income countries, is one that is not fully appreciated by many governments and the majority of development and disaster specialists (Moser and Satterthwaite, 2008; Rossetto, 2007). Low- and middle-income countries, with close to three-quarters of the world's urban population, are at greatest risk from extreme events and also have a far greater deficit in adaptive capacity than do high-income countries because of backlogs in protective infrastructure and services and limitations in urban government (Moser and Satterthwaite, 2008; Satterthwaite et al. 2007).

An inevitable result of the increased damages to infrastructure from climate change and disasters will be a dramatic increase in the resources needed to restore infrastructure and assist the poor who will be most affected by damaged infrastructure (Freeman and Warner, 2001). A study by the Australian Academy of Technological Sciences and Engineering (ATSE) concluded that retrofit measures will be needed to safeguard existing infrastructure in Australia and new adaptation approaches will be required for construction of new infrastructure (Stevens, 2008). The recommendations from this study as well as those from other countries recognize the need for: research to fill gaps on the future climate, comprehensive risk assessments for existing critical climate sensitive infrastructure, development of statistical information on future climate change events, investigation of the links between soft and hard engineering solutions and strengthened research efforts to improve the modelling of small-scale climate events (Stevens, 2008; Wilby, 2008; Auld, 2008a). The recommended adaptation options to deal with projected impacts to the built environment range from deferral of actions pending new information to modification of infrastructure components, acceptance of residual losses, reliance on insurance and risk transfer instruments, formalized asset management and maintenance, new structural materials and practices, improved emergency services and retrofitting and replacement of infrastructure elements (Stevens, 2008; Wilby, 2007; Wilby et al, 2009; Auld, 2008a; Neumann, 2009).

Planning for safe structures is a key disaster risk management and adaptation approach towards reducing vulnerabilities today and into the future. The implementation of adequate building codes incorporating regionally specific climate data and analyses can improve resilience for many types of risks (World Water Council, 2009; Wilby et al, 2009; Auld, 2008a). Typically, infrastructure codes and standards in most countries use historical climate analyses to climate-proof new structures, relying on the assumption that the past climate will represent the future. For example, water related engineering structures, including both disaster- proofed infrastructure and services infrastructure (e.g. water supply, irrigation and drainage, sewerage and transportation), are all designed using analysis of historical rainfall records, assuming that the past climate will represent the future (Wilby and Dessai, 2010, Auld, 2008a). Since infrastructure is built for long life-spans and the assumption of climate stationarity will not hold for future climates, it is important that climate change guidance, tools and adaptation options be developed to ensure that climate change can be incorporated into infrastructure design (Stevens, 2008; Wilby et al, 2009; Auld, 2008b).

Many climate change studies advocate a twin-track approach of: (1) "bottom-up" vulnerability assessments of strategies to cope with present climate extremes and variability, and, (2) "top-down" approaches to develop climate change tools and scenarios to evaluate sector-specific, incremental changes in risk over the next few decades (Wilby et al, 2009; Auld, 2008b). Although the "top-down" approach of using climate scenarios for impact assessment has grown steadily since the 1990s, uptake of such information into adaptation decision-making is lagging (Wilby et al, 2009). Some tools are becoming available to account for changing climate risks. These tools include the avoidance of high-risk areas through more stringent development controls, allocation of green space for urban cooling and flood attenuation, appropriate building design and climate sensitive planning, new hard engineering codes and standards with increased uncertainty/safety factors and climate change guidance and incorporation of climate change into engineering practices especially for flood defences and water supply systems (Wilby, 2007; Auld, 2008a; Neumann, 20009). To address ongoing climate change in the Arctic, the Canadian Standards Association released a national Guide in 2010 to deal with climate change risks in melting permafrost regions by incorporating results from an ensemble of climate change models into risk assessment and risk management methodologies (NRTEE, 2009; Canadian Standards Association, 2010; see Chapter 9 case study 9.x.x on vulnerable regions: The Arctic). Overall, prioritization of required adaptation actions for the built environment will need to account for existing and future vulnerabilities, the variable lifecycles of structures and replacement and maintenance cycles (Auld, 2008a).

In developing countries, structures are often built using best local practices. But, problems can arise when the best local practices do not incorporate the use of building standards or inadequately account for local hazards (Rossetto, 2007). While the perception in some developing countries is that building codes and standards are too expensive, the implementation of incremental hazard-proof measures in building structures has proven in some countries to be relatively inexpensive and highly beneficial in reducing losses (ProVention, 2009; Rosetto, 2007; see Chapter 9 case studies 9.x.x). For example, Bangladesh has implemented simple modifications to improve the cyclone-resistance of (non-masonry) kutcha or temporary houses, with costs that amounted to only 5 per cent of the construction costs (Lewis and Chisholm, 1996; Rossetto, 2007). In reality, the most expensive component to codes and standards is usually the cost to implement national policies for inspections, knowledge transfer to trades and their up-take and implementation (Rossetto, 2007). Bangladesh is also developing national policies requiring that houses built following disasters include a small section of the replacement house that meets "climate proofing" standards and acts as a household shelter in the next disaster. In many countries, climate proofing guidelines and standards are applied to structures that are used as emergency shelters and for structures that form the economic and social lifeline of a society, such as its communications links, hospitals and transportation networks (Rossetto, 2007).

Land and water use planning to protect and enhance "green infrastructure" or natural buffers and defences for the built environment can reduce vulnerabilities to current and future climate change. For example, stormwater management or urban flood management approaches (*references from Canberra, Florida, Japan and Malaysia*) have been developed over the last decades using soft and hard engineering approaches to overcome flash floods and poor water quality in natural systems in rapidly urbanised areas. Current flood proofing of the existing infrastructure, including modification of existing structures and their operations and maintenance, is expected to incorporate projected extreme rainfalls from an ensemble of climate models into design criteria. While some countries' authorities, such as government departments responsible for building regulations and the insurance industry, are taking the reality of climate change very seriously, challenges remain on how to incorporate the uncertainty of future climate predictions, especially for elements such as extreme winds and extreme precipitation and its various phases (e.g. short and long duration rainfalls, freezing rain, snowpacks), into formal legislation (Wilby, 2010; Auld, 2008a; Sanders and. Phillipson, 2003)

6.3.3.2.2. Promoting human development and secure livelihoods and reducing vulnerability

Vulnerabilities to climate related hazards vary between and within countries due to factors such as poverty, social positioning, geographic location, gender, age, class, ethnicity, community structure, community decision-making processes and political issues (Yodmani, 2001). Between countries, policies and measures such as the establishment of a LDC fund, Special Climate Fund, Adaptation Fund, climate change Multi-Donor Trust Fund etc., have all been developed to address the special adaptation needs of these most vulnerable countries (see Section 7.4.3 for more details). Within countries, the most vulnerable are usually those least able to cope with climate hazards due to limited adaptive capacity and policies are needed to increase this capacity (Davies et al, 2009; Heltberg et al., 2009).

The most vulnerable communities in poor countries may require full scale assistance to protect lives, properties and livelihoods (ISDR, 2009b). In many countries, including those in Africa, vulnerable communities suffer greater water stress, food insecurity, disease risks and loss of livelihoods (IPCC, 2007; FAO, 2008). For example, climate change is likely to increase risks for waterborne diseases for many, requiring targeted assistance for health and water sanitation issues (Curriero, 2001; IPCC, 2007). Resilient housing and safe shelters will remain as one of the key priorities to protect the vulnerable from disasters and climate extremes, requiring national guidelines to ensure that new or replacement structures are built with flexibility to accommodate future changes (Rossetto, 2007; Auld, 2008). Small island states and low-lying countries may require support that relocates vulnerable groups to safer locations or other countries, all requiring a complex set of actions at the national and international levels (IPCC, 2007).

While there is a lot of rhetoric about targeting assistance to most vulnerable in the developing world, practical “on the ground” examples have so far remained limited (Ayers and Huq, 2009). Nonetheless, some developing countries have implemented successful policies and plans. For example, social safety nets and other similar national level programmes, particularly for poverty reduction and attainment of MDGs etc., have helped the poorest to reduce their exposure to current and future climate shocks (Davies et al, 2009; Heltberg et al., 2008). Some examples of social safety nets are cash transfers to the most vulnerable, weather-indexed crop insurance, employment guarantee schemes and asset transfers (Davies et al., 2009; CCCD, 2009). A national policy to help the vulnerable build assets should incorporate climate screening in order to remain resilient under a changing climate (UN-ISDR 2004; Davies et al., 2009; Heltberg et al., 2008). Other measures such as social pensions that transfer cash from the National level to vulnerable elderly people provide buffers against climate shocks (Davies et al, 2009; Heltberg et al., 2008). However, lack of capacity and good governance has remained a major barrier to efficient and effective delivery of assistance to most vulnerable (UNDP, 2007; Warner et al., 2009; CCCD, 2009).

A crucial aspect in reducing vulnerability of climate-related risks - including food insecurity - is to make climate-related and climate change information available and accessible to decision-makers (Wilby et al., 2009; Washington et al., 2006). The use of climate information in the national planning and programming process is still in its infancy. A recent ‘gap analysis’ in Africa showed that while climate information exists that could aid decision makers in making ‘climate smart’ decisions, this information is seldom incorporated (Ayers and Huq, 2009). In many developing countries, one of the potential barriers for identifying the most vulnerable regions and people under future climate change is the limited capacity to downscale global and regional climate projections to a scale needed to support national level planning and programming process (Wilby et al., 2009; CCCD, 2009; Washington et al., 2006).

A process has already been initiated in many countries to establish a solid information base and support the prioritization of adaptation needs for the most vulnerable populations. For example, National Adaptation Programme of Actions (NAPA) have been able to assess the climate sensitive sectors and prioritize projects to address the urgent adaptation needs of the most vulnerable regions, communities and populations in 49 least developed countries (UNCTAD, 2008).

6.3.3.2.3. Investing in natural capital and ecosystem-based adaptation

Investment in sustainable ecosystems and environmental management has the potential to produce triple wins – reduction in underlying risk factors (UNISDR, 2007, UNEP 2006, 2009 and Sudmeier-Rieus and Ash 2009), improved livelihood and conservation of biological diversity - through sustainable management of biological resources and, indirectly, through protection of ecosystem services (UNEP 2006, 2009; World Bank 2009).

Healthy natural ecosystems (see Section 6.3.1 and Box 6-4) have a critical role to play in reducing risk of climate extremes and disasters (UNEP, 2009; Bebi, 2009; Dorren, 2004; Phillips and Marden, 2005; Sidle et al., 1985; SDR, 2005a, b; ISDR, 2007, 2009; Colls et al., 2009; Sudmeier-Rieux and Ash 2009; Reid and Huq, 2005; Secretariat of the Convention on Biological Diversity, 2009). Investment in natural ecosystem has long been used to reduce risks of disasters. Forests, for example, have been used in the Alps and elsewhere as effective mitigation measures against avalanches, rockfalls and landslides (Bebi, 2009; Dorren, 2004; Phillips and Marden, 2005; Sidle et al., 1985). The damage caused by wildfires, wind erosion, drought and desertification can be buffered by forest management, shelterbelts, greenbelts, hedges and other "living fences" (Dudley et al., 2010; ProAct, 2008). Mangroves could reduce 70-90% of the energy from wind generated waves in coastal areas, depending on the health and extent of the mangroves (UNEP, 2009). Investment in natural ecosystem can also contribute significantly to reduction in GHG emissions, through practices such as Land Use, Land Use Change and Forestry or LULUCF and through Reduced Carbon Emissions from Deforestation and Forest Degradation or REDD (UNEP, 2006; Secretariat of the Convention on Biological Diversity, 2009).

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Box 6-4 Value of Ecosystem Services in Disaster Risk Management: Some Examples

1) In the Maldives, degradation of protective coral reefs necessitated the construction of artificial breakwaters at a cost of US$ 10 million per kilometre (Secretariat of the Convention on Biological Diversity, 2009).
2) In Viet Nam, the Red Cross began planting mangroves in 1994 with the result that, by 2002, some 12,000 hectares of mangroves had cost US$1.1 million for planting but saved annual levee maintenance costs of US$ 7.3 million, shielded inland areas from a significant typhoon in 2000, and restored livelihoods in planting and harvesting shellfish (Reid and Huq, 2005; Secretariat of the Convention on Biological Diversity, 2009).
3) In the United States, wetlands are estimated to reduce flooding associated with hurricanes at a value of US$ 8,250 per hectare per year, and US$ 23.2 billion a year in storm protection services (Constanza et al., 2008).
4) In Sri Lanka Data from two villages in Sri Lanka that were hit by the devastating Asian tsunami in 2004 show that while two people died in the settlement with dense mangrove and scrub forest, up to 6,000 people died in the village without similar vegetation (World Bank, 2009)

Source: Sudmeier-Rieux and Ash (2009)

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REDD and REDD+ related strategies can help generate alternative sources of local communities and provide much needed financial incentives to prevent deforestation (Angelsen, et al 2009 Sudmeier-Rieux and Ash 2009; Reid and Huq, 2005; Secretariat of the Convention on Biological Diversity, 2009), and improve their livelihoods. Livelihood benefits are derived from protection of natural ecosystem and goods and services they support and conservation of biological diversity (International Union for the Conservation for Nature and Natural Resources, Stockhom Environment Institute et al. 2003; Longley and Maxwell 2003; Millennium Ecosystem Assessment 2005; SEEDS 2008).

With improvements on economic well being and associated human development conditions, vulnerability to risks of climate extremes and disasters are also expected to be reduced (Benson and Clay 2004; Lal, Singh et al. 2009). The extent to which ecosystems support such benefits though depends on a complex set of dynamic interaction of ecosystem related factors, as well as the intensity of the hazard (Sudmeier-Rieux and Ash, 2009) and institutional and governance arrangements (see various case studies in Angelsen, et al 2009). For example, coastal forests, stabilized sand dunes, mangroves and seagrasses are all known to reduce impact forces, flow depths and velocities of storm surges, while the protective effects against tsunami waves and storm surges is more dependent on factors such as coastal bathymetry, coastal forest and mangrove stand density (Baird et al. 2005; Balmford et al, 2008; Björk et al. 2008; IOC, 2009; Kaplan et al., 2009; Yanagisawa, 2009). Scientific relational understanding between ecosystem health and the reduction of risks associated with climate extremes and disaster risks is though limited. There are nonetheless, many examples where countries have rehabilitated natural ecosystems, that demonstrate the nature of economic benefits that natural ecosystems provide in reducing risks to disasters (Reid and Huq, 2005; Secretariat of the Convention on Biological Diversity, 2009 (see Box 6-4).

Some countries have begun to explicitly integrate ecosystem based adaptation as a key strategy for addressing climate change, integrating such strategies in national and sectoral development planning. (see Box 6-5).

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Box 6-5. Some Examples of Ecosystem-Based Adaptation (EbA) Strategies and Disaster Risk Management Successes

Viet Nam has applied Strategic Environmental Assessments to land use planning projects and hydropower development for the Vu Gia-Thu Bon river basin (OECD, 2009; Secretariat of the Convention on Biological Diversity, 2009?). European countries affected by severe flooding, notably the U.K., the Netherlands and Germany, have made policy shifts to “make space for water” by applying more holistic River Basin Management Plans and Integrated Coastal Zone Management (EC, 2009; DEFRA, 2005;Wood et al. 2008). At the regional level, the Caribbean Development Bank has integrated disaster risk into its Environmental Impact Assessments for new development projects (ISDR, 2009 and CDB and CARICOM, 2004). Under Amazon Protected Areas Program, Brazil has created over 30 million ha mosaic of biodiversity-rich forests reserve of state, provincial, private, and indigenous land, resulting in potential reduction in emissions estimated at 1.8 billion tons of carbon through avoided deforestation {World Bank, 2009). Swiss Development Cooperation’s four year project in Muminabad, Tajikistan adopted an integrated approach to risk through reforestation and integrated watershed management (SDC, 2008).

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Generally, EbA strategies, often referred to as ‘soft’ options, can be more cost-effective CCA strategy than hard infrastructures and engineering solutions, and produce multiple benefits. EbA options are often more easily accessible to the rural poor (Sudmeier-Rieux, 2009). But countries would need to overcome many challenges if countries are to be successful in increasing investment in nature based solutions, including for example:

- Insufficient recognition of the economic and social benefits of ecosystem management under current risk situations let alone under increased risks of climate change extremes and disasters (Vignola et al, 2009).
- Lack of interdisciplinary science and implementation capacity for making informed decisions associated with complex and dynamic systems and inter-ministerial coordination and planning for EbA which may follow administrative, rather than geographical boundaries such as watersheds (OECD, 2009; Leslie and McLeod, 2007).
- Lack of capacity to undertake careful assessments of alternative strategies to inform choices at the micro level. Such assessments could provide total economic value of *in situ* conservation compared with alternative uses of the forested land such as in agriculture (see eg Balmford 2002). Such assessments can help between *in situ* conservation and *ex-situ* conservation strategies, for example, species relocation, assisted migration, captive breeding, and *ex-situ* storage of genetics or germplasm, may be less cost effective than *in-situ* conservation actions (Convention on Biological Diversity’s Ad Hoc Technical Expert Group (Secretariat of the Convention on Biological Diversity, 2009).
- Data and monitoring on ecosystem conditions and risk are often dispersed across agencies at various scales and are not always accessible at the sub-national or municipal level where land use planning decisions are made (ISDR, 2009a).
- Absence of tools to assess and monitor impact of climate change on biodiversity and ecosystem (Secretariat of the Convention on Biological Diversity, 2009).

6.3.3.3. Transferring and Sharing ‘Residual’ Risks

Risks can be reduced at all levels using many different measures, yet some residual risks will remain due to physical, financial and other constraints. Implicitly, residual risk is borne after an event when people use their personal savings or governments use their tax revenue (the latter often also called ex post loss financing). Ex ante risk financing occurs when risk is considered explicitly before disaster events using risk sharing and transfer instruments. The relevance and role of such ex ante and ex post mechanisms for national level strategies for managing extreme events is demonstrated by a substantial body of literature (e.g., Jaffee and Russell, 1997; Van Schoubroeck, 1997; Kunreuther, 1998, 2000; Froot, 1999; Von Ungern-Sternberg, 2002; Lane, 2004; Schwarze and Wagner, 2004; Mills, 2009; Aakre et al., 2010; Hochrainer, Bayer and Mechler, 2010). Risk financing as an important pre-event risk management tool for developing and emerging economies has been discovered, applied and analyzed over the last ten years, as reflected by a growing body of literature (eg., Pollner, 2000; Andersen, 2001; Varangis, Skees and Barnett, 2002; Auffret, 2003; Dercon, 2005; Linnerooth-Bayer, Mechler and Pflug, 2005; Hess and Syroka, 2005; World Bank, 2007; Skees, 2008; Cummins and Mahul, 2008; Hess and Hazell,,2009). Finally the role of risk financing for climate change was first covered a decade ago, but has only lately received growing attention (e.g., Doherty, 1997; Tol, 1998; IPCC, 2001; Mills, 2005; AOSIS, 2007; MCII, 2008; Linnerooth-Bayer, Bals and Mechler, 2008).

Markets can often provide risk financing solutions, albeit partial ones given market failures and market gaps. Market mechanisms may work less well in developing countries, particularly because there is often little or no supply of insurance instruments. In such circumstances, governments may need to create enabling environments for the private sector to become more engaged or offer insurance themselves. Employing insurance and other risk financing instruments for helping to manage the vagaries of nature generally involves the building of public private partnerships in developing and in developed countries due to market failure, adverse selection and the sheer non-availability of such instruments (see Aakre et al., 2010). Because of such reasons, there is a role for governments to not only create enabling environment for private sector engagement, but also to regulate their activities. Hess and Hazell (2009) distinguish between protection and promotion models, while acknowledging that in many instances hybrid combinations may contain elements of both. Protection relates to governments helping to protect themselves, individuals and business from destitution and poverty by providing ex post financial assistance, which however is taken out as an ex ante instrument as insurance before disasters. The promotion model relates to the public sector promoting more stable livelihoods and higher income opportunities by better helping businesses and households access risk financing, including micro-financing**.**

In many instances, insurance providers even in industrialized countries have been reluctant to offer region- or nation-wide policies covering flood and other hazards because of the systemic nature of the risks, as well as problems of moral hazard and adverse selection (Froot, 2001; Aakre, 2010). Insurance policies in Europe may be bundled with household insurance, or offered on a stand-alone basis; governments may pay a premium on behalf of the insured or governments may choose to (also) compensate post event; insurance may be compulsory (Prettenthaler et al., 2004; Schwarze, 2004; Aakre et al., 2010). Even where insurance markets do exist, there is a wide variety of schemes and penetration is never often much less than 100%. In some highly exposed countries, such as the Netherlands for flood risk, insurance is even virtually non-existent.

Because private insurers are often not prepared to fully underwrite the risks, many countries, including Japan, France, the US, Norway and New Zealand, have legislated public-private national insurance systems for natural perils with mandatory or voluntary participation of the insured as well as single hazard and comprehensive insurance. Also, in order to increase market penetration of non-traditional risks, such as in fledgling micro-insurance schemes, different strategies are being employed, including, as one example of pro-poor regulation in India shows, that insurers within their regular business segment reserve a certain quota for low income policies, effectively leading to a cross-subsidization of the micro-insurance industry (Mechler, Linnerooth-Bayer and Peppiatt, 2005).

Governments have a responsibility for a large portfolio of public infrastructure assets that are at risk to disasters. Moreover, most governments are obligated to provide post-disaster emergency relief and assistance to vulnerable households and businesses. Governments of developing countries typically finance their post-disaster expenses by diverting from their budgets or from already disbursed development loans, as well as by relying on new loans and donations from the international community (see Mechler, 2004). In the past, these post-disaster sources of finance have often proven woefully inadequate to assure timely relief and reconstruction in developing countries. What is more, post-disaster assistance is not only often inadequate, but it can discourage governments and individuals from taking advantage of the high returns of preventive actions (Gurenko, 2003).

In wealthy countries, government insurance hardly exists at the national level and in Sweden insurance for public assets is illegal (Bayer and Amendola, 2000), although states in the US, Canada and Australia, regulated not to incur budget deficits, often carry cover for their public assets (Burby, 2001). As discussed earlier, this is consistent with Arrow and Lind Theorem, which suggests that governments can spread risk over its citizens, most usually by means of taxation; then, the expected and actual loss to each individual taxpayer is minimal due to the sheer size of the population. Second, a government's relative losses from disasters in comparison with its assets may be small if the government possesses a large and diversified portfolio of independent assets. Neither of this however, applies to small, low-income and highly exposed countries that have over-stretched tax bases and highly correlated infrastructure risks (OAS, 1991; Pollner, 2001; Mechler, 2004; Cardona, 2006; Linnerooth and Bayer, 2007; Ghesquiere and Mahul, 2007). Realizing the shortcomings of after-the-event approaches for coping with disaster losses, sovereign insurance may become an important cornerstone for tackling the substantial and increasing effects of natural disasters (Ghesquiere and Mahul, 2007).

A common recourse of action has been to insure public sector relief expenditure, and key applications have been in Mexico in 2006 and in the Caribbean with the Caribbean Catastrophe Risk Insurance Facility (CCRIF) (Cardenas et al., 2007; Ghesquiere, et al., 2006). These transactions are likely to set an important precedent for protecting highly exposed developing and transition country governments against the financial risks of natural catastrophes. Like national governments, donor organizations, exposed indirectly through their relief and assistance programs, too, have considered purchasing insurance. The World Food Programme, for example, purchased protection for its drought exposure in Ethiopia through index-based reinsurance (see case study in Chapter 9).

6.3.3.4. Managing the Impacts

Risk reduction strategies cannot completely eliminate the impact of extreme climate events (Katoch, 2007).and the impacts of climate-related disasters still need to be managed even if the practices detailed above are executed perfectly. Moreover, the immediate post-disaster period and those associated with rehabilitation and reconstruction often provide significant opportunities to put in place new systems, policies and practices with the intention of reducing future disaster risk and adapting to climate change.

Climate related disasters have played a major role in the increasing human impact of overall disasters, according to the IFRC (2009), and undoubtedly have put a strong pressure on humanitarian organizations and national governments. Table 6-4 shows that in the 1999-2008 period near 97% of affected persons were attributed to disasters provoked by drought, floods, heat waves or other climate related hazards. The remaining 3% were affected by geological related disasters, especially earthquakes and volcanic eruptions (IFRC, 2009). When assessing economical losses the trend stays the same, with geological-related disasters accounting for only 21.8% of total damages and climate related disasters accounting for 78.2% of the same total (IFRC, 2009).Considering the present trends of risk and climate change, the humanitarian costs will probably even rise in the near future, some estimations point out that increase could range from a 32% due to changes in frequency of disasters, to upwards of a 1600% increase when an increase in intensity of disasters is taken into account (Webster, et al., 2008).

[INSERT TABLE 6-4 HERE:
Table 6-4: Total number of people reported affected, by type of phenomenon and by year (1999 to 2008), in thousands.]

In practice, national governments rely on humanitarian organizations, usually integrated in the national systems, for dealing with the human toll of disasters. One of the major actors in the humanitarian scene are, undoubtedly, the Red Cross and the Red Crescent, and they are also addressing the challenges posed by disaster risk reduction and climate change impacts very seriously, as well as another large practitioners of the humanitarian field (IASC, 2009; IFRC, OCHA and WFP, 2009; Red Cross/Red Crescent, 2007). A comprehensive review of experiences at the national level pointed out at six components of the so called "good climate risk management": (a) climate risk assessment: assessing priorities, and planning follow-up; addressing the consequences: (b) integrating climate change in programs and activities; (c) raising awareness; (d) establishing and enhancing partnerships; (e)international advocacy: shaping the global response to climate change; and (f) documenting and sharing experiences and information (Red Cross/Red Crescent, 2007).

Different efforts made under the framework of climate change adaptation are increasingly including preparedness and response measures such as training, equipment, EWS, health protection, natural resource development, environmental management and livelihoods protection, for example (IASC, 2009; Barret et al., 2007; McGray, 2007). The use of climate information has been another field in which humanitarian efforts have been undertaken, nevertheless, serious challenges remain in the use of climate information in humanitarian decision-making for example: forecasts give only probabilities, not certainties, leaving disaster managers to use their own criteria to interpret seasonal forecasts and its implications on operations; and second, the further in advance a forecast is made, the less accurate it is likely to be so, at the end, the preparedness period is always short and uncertain. (IASC, 2009).

Case studies are showing an important shift in the humanitarian sector from the preparedness-response approach to the disaster risk reduction and climate change adaptation approaches, at the same time, adaptation projects are also including preparedness and response components (IASC, 2009a). At the national level these trends are evident in different programs of international cooperation and humanitarian organizations as well as in the growing involvement of national governments in disaster response, risk reduction and climate change adaptation (ISDR, 2009). But despite the obvious progress done in its field, there are also big problems and challenges that have been identified when evaluating the disaster preparedness and response capabilities: lack of appropriate policies and legislation; decentralization of capacities and resources; insufficient budgetary allocation; capacity building at the local level; lack of political will to include disaster risk reduction activities in traditional emergency response programs (UNISDR, 2004; ISDR, 2009).

6.4. Aligning National Disaster Risk Management Systems to the Challenges of Climate Change and Development

As has been mentioned in the above, climate change presents multidimensional and fundamental challenges for national systems for managing the risks of climate extremes and disaster risks, including potential changes to the way society views, treats and responds to risks. As climate change is altering the frequency and magnitude of some extreme events and helping to create more extreme impacts through amplifying vulnerability and exposure and increasing uncertainty in some areas (see Chapters 3 and 4), the efficacy of national systems requires review and realignment with the new challenges. At minimum, national systems must begin to integrate the assessments of climate impacts and changing disaster risks and uncertainties into current investments, strategies and activities, seek to strengthen longer term capacity of all actors to adapt to climate change and address the drivers of vulnerability and poverty, recognising climate change as a key driver (UN-ISDR GAR 2009; Schipper 2009). In practice, this might require new alliances across government and potentially between countries, different actors to join the national system, a reallocation of responsibilities and resources across scales and new practices. As a compliment the available data, information and knowledge about the impact of climate change and disaster risk presented in Chapter 2, 3 and 4, this section seeks to elaborate the key areas where realignment of national systems must occur – in assessing the effectiveness of disaster risk management in a changing climate (6.4.1), managing uncertainty and adaptive management (6.4.2), tackling poverty, vulnerability and their structural causes (6.4.3) and supporting the transition to a low carbon form of development that appreciates the implications of changing disaster risks (6.4.4)

6.4.1. Assessing the Effectiveness of Disaster Risk Management in a Changing Climate

In order to align disaster risk management with the challenges presented by climate change, it is necessary to assess the effectiveness and efficiency of management options in a changing climate based on the best available information, recognising that this information is patchy at best. This section assesses the literature from both disaster risk management and climate change adaptation on the effectiveness of different options from an economics perspective. Studies framed around climate adaptation for developed and developing countries have focused on the costs of adaptation rather than impacts and damage costs as well as jointly considering costs and benefits (see UNFCCC, 2009; World Bank, 2009; EEA, 2007; ECA, 2009; Solomon 2007; Nordhaus, 2007; Parry, 2009; Agrawala and Fankhauser, 2008). National level studies in the EU, UK, Finland and the Netherlands, as well as in a larger number of developing countries, using the NAPA approach, have been conducted or are underway (Lemmen et al, 2008; MMM, 2005; Van Ierland, 2005; DEFRA, 2006; UNFCCC, 2009). Yet, the evidence base on the economic efficiency , that is benefits net of cost assessments, of adaptation remains limited and fragmented (Adger et al., 2007; Agrawala and Fankhauser, 2008; UNFCCC, 2009). In the disaster risk management literature, too, there have been very few national level assessments focussing on economic efficiency of management responses (see World Bank, 1996; Benson 1998; Mechler (2004)),

Where such assessments of costs and benefits of alternative options have been undertaken, most of these studies have focused on sea level risk and slower onset impacts on agriculture (UNFCCC, 2009; Agrawala and Fankhauser, 2008. Such studies have generally adopted deterministic impact metrics, which is problematic for disaster risk particularly in a environment where frequency and variability of extreme events is changing. On the other hand, assessments of variability in a changing climate are generally difficult to establish and mostly not available for many hazards (see Mechler *et al.*, 2010).

Several different methods have been advocated for explicitly aligning disaster risk management with climate change considerations. A recent, risk-focused study (ECA, 2009) suggested the use of an adaptation cost curve approach, which organizes adaptation options around their cost benefit ratios. Interestingly, many of the options considered efficient are of what are considered to be “soft” options, such as reviving reefs, using mangroves as barriers and nourishing beaches. Clearly, many caveats and uncertainties apply to establishing such cost-curves, and this assessment, as one example, is based on asset losses rather than income-based outcomes and opportunity costs. Apart from proper cost benefit analyses, a selected number of studies using a multi criteria approach have been conducted (see Van Ierland, 2005; de Bruin et al. (2009). De Bruin et al. (2009) describe a hybrid approach based on qualitative and quantitative assessments of adaptation options for flood risk in the Netherlands. For the qualitative part, stakeholders selected options in terms of their perceived importance, urgency and other elements. In the quantitative assessment costs and benefits of key adaptation options are determined. Finally using priority ranking based on a weighted sum of the qualitative and quantitative criteria suggests that in the Netherlands an integrated portfolio of nature and water management with risk based policies has particular high potential and acceptance. Overall, the costing and assessment of adaptation explicitly considering the risk based nature of extreme events remains incipient, and more work is desirable.

6.4.2. Managing Uncertainties and Adaptive Management in National Systems

Disasters associated with climate extremes are inherently complex, involving socio-economic as well as environmental and meteorological uncertainty. Population, social, economic and environmental change all influence the way in which hazards are experienced, through their impact on levels of exposure and on people’s sensitivity to hazards (Pielke Jr. et al. 2003). Uncertainty about the magnitude, frequency and severity of climate extremes is managed, to an extent, through the development of predictive models and early warning systems. Yet uncertainty pervades climate and weather models from the initial theoretical foundations to model parameters (Murphy et al. 2004; Stainforth et al. 2005). Early warning systems are also based on models and consequently there is always a probability of their success (or failure) in predicting events accurately, although the failure to heed early warning systems is also a function of social factors, such as trust in the information-providing institution, previous experience of the hazard, degree of social exclusion, and gender (see for example Drabek 1986; Drabek 1999). Enhanced scientific modeling and interdisciplinary approaches to early warning systems can address some of these uncertainties provided good baseline and time series information is available. Even where such information is available, there remain other uncertainties that influence the outcome of hazards. These relate to the capacity of ecosystems to provide buffering services, and the ability of systems to recover. Management approaches that take uncertainty into account include adaptive management and resilience, yet these approaches are not without their challenges.

Adaptive management has come to mean the testing of hypotheses through management action and the bringing together interdisciplinary science, experience and traditional knowledge into decision making through “learning by doing” (Walters 1997). In most cases it is implemented at the local or regional scale and there are few examples of its implementation at the national level. Proponents argue that effective adaptive management contributes to more rapid knowledge acquisition, better information flows between policy makers, and ensures that there is shared understanding of complex problems (Lee, 1993). Examples abound of adaptive management in ecosystem management (Johnson 1999; Ladson and Argent 2002) and in disaster risk reduction (Thomson and Gaviria, 2004; Tompkins, 2005). One of the main unresolved issues in adaptive management is how to ensure that scientists and engineers tasked with investigating adaptation and disaster risk management processes are able to learn and how this learning can be fed into policy and practice. In the case of the restoration of the Florida Everglades a limiting factor to effective management is the unwillingness of some parts of society to accept short term losses for longer term sustainability of ecosystem services (Kiker et al. 2001). Investment in hurricane preparedness in New Orleans prior to Hurricane Katrina provides a contemporary example of science not being included in disaster risk decision making and planning (Congleton 2006; Laska 2004).

Testing new approaches to disaster risk management can only be undertaken effectively if the management institutions are scaled appropriately, where necessary at the local level (Berkes 2004), or at multiple scales with effective interaction (Gunderson and Holling 2002). For the management of climate extremes, the appropriate scale is influenced by the magnitude of the hazard and the affected area. Research suggests that increasing biological diversity of ecosystems allows a greater range of ecosystem responses to hazards, and this increases the resilience of the entire system (Elmqvist et al, 2003). Other research has shown that reducing non-climate stresses on ecosystems can enhance their resilience to climate change. This is the case for coral reefs (Hughes et al. 2003; and Hoegh-Guldberg, et al., 2009), and rainforests (Malhi et al 2008). Managing the resources at the appropriate scale, e.g. water catchment or coastal zone instead of managing smaller individual tributaries or coastal sub-systems (such as mangroves), is becoming more urgent (Parkes and Horwitz 2009; Sorenson 1997)

Spare capacity within institutions has been argued to increase the ability of socio-ecological systems to address surprises (Folke et al. 2005). McDaniels et al (2008) in their analysis of hospital resilience to earthquake impacts, agreed with this finding, concluding that key features of resilience include the ability to learn from previous experience, careful management of staff during hazard, daily communication and a willingness by staff to address specific system failures. The latter can be achieved through creating overlapping institutions with shared delivery of services/functions, and providing redundant capacity within these institutions thereby allowing a sharing of the risks (Low et al. 2003). Such redundancy increases the chances of social memory being retained within the institution (Ostrom 2005). However, if carefully managed, the costs to this approach can include fragmented policy, high transactions costs, duplication, inconsistencies and inefficiencies (Imperial 1999).

Nearly forty years of research have produced evidence of the impacts of aspects of resilience policy (notably adaptive management) on forests, coral reefs, disasters, and adaptation to climate change, however most of this has been at the local or ecosystem scale. There is still little evidence of the implementation of resilience policy at the national scale. Climate resilience as a development objective is difficult to implement, particularly as it is unclear as to what resilience means (Folke, 2006). Unless resilience is clearly defined and broadly understood, with measurable indicators to show the success, the potential losers from this policy may go unnoticed, causing problems with policy implementation and legitimacy (Eakin et al. 2009).

6.4.3. Tackling Poverty, Vulnerability, and their Structural Causes

Chapters 2 and 4 suggest that climate change may exacerbate vulnerability and exposure, which may potentially lead to more extreme impacts. This increases the urgency for disaster risk management systems to more effectively tackle the underlying drivers and root causes of poverty and vulnerability, something that so far it has struggled to do (UN-ISDR 2010), while also recognizing that climate change itself is one of these drivers; posing new challenges for considering the environmental and carbon emissions dimensions of disaster risk management activities (covered in Section 6.4.4). As discussed in Chapter 2, underlying drivers and root causes of vulnerability and poverty include, inequitable development, declining ecosystems, lack of access to power, basic services, land and weak governance (ISDR, 2009) .Climate change adaptation and disaster risk reduction share a common goal in seeking to reduce vulnerability – addressing inequity, promoting secure livelihoods, discrimination, and increasing access to power and resources, among others (Mitchell and Van Aalst 2008, Tanner and Mitchell 2008, Schipper 2009). However, strategies for tackling the risks of climate extremes and disasters adaptation and disaster risk management used in practice tend to focus on treating the symptoms of vulnerability, and with it risk, rather than the underlying causes, and these are not sufficiently embedded in sustainable development (Schipper 2009).The mid-term review of the HFA indicates that insufficient effort is being made to tackle the conditions which create risk (UN-ISDR 2010). This is despite a highly evolved awareness of the drivers of vulnerability to extreme events (Wisner *et. al.* 2004, CCCD

2009), highlighting a disconnect between disaster risk management and development processes that tackle the structural causes of poverty and vulnerability, and between knowledge and implementation at all scales (UNISDR 2009).

This raises questions about the alignment of current national risk management systems and poverty and vulnerability reduction approaches and to what extent climate change provides an opportunity to recreate this link in an innovative way (Soussan and Burton 2002). One option discussed in the literature that aims to recreate this link involves investing in and strengthening social protection/welfare/safety net measures within national development programmes designed to tackle the causes of poverty and vulnerability while also addressing risk in a changing climate at the same time (Davies et al. 2008, see Box 6-6).

_____ START BOX 6-6 HERE _____

Box 6-6. Linking Disaster Risk Reduction, Climate Change Adaptation, and Transformative Social Protection

Adaptive Social Protection (ASP) is the combination of social protection (SP), disaster risk reduction (DRR) and climate change adaptation (CCA) in policy and practice as a means to promote climate and disaster-resilient livelihoods in developing countries. Social protection is the set of all initiatives, both formal and informal, that provide social assistance to extremely poor individuals and households; social services to groups who need special care or would otherwise be denied access to basic services; social insurance to protect people against the risks and consequences of livelihood shocks; and social equity to protect people against social risks such as discrimination or abuse (Devereux and Sabates-Wheeler 2004). ASP recognises that the disciplinary concepts and knowledge sets from the thematic areas of SP, DRR and CCA have their own strengths and weaknesses, and work to maximise the advantages that each brings to poverty and vulnerability reduction among the poorest and most vulnerable (Davies et al. 2008; Davies et al. 2009; Cyprik 2009; Heltberg et al. 2009; Heltberg and Siegel 2008). This is important given the requirement to significantly scale up vulnerability-reducing programmes and projects in response to climate change and shifting disaster risk in a way that maximises development impact whilst avoiding duplication of effort on the ground. Importantly, merging a transformative version of social protection (Devereux and Sabates-Wheeler 2006), which recognises that poverty and vulnerability cannot be tackled through resource transfers alone and without addressing underlying issues of disempowerment and inequality, with disaster risk management and climate change adaptation provides a framework to sustainably tackle the drivers and root causes of disaster risk. Table 6-5, shows the benefits of different social protection measures for disaster risk reduction and climate change adaptation (Davies *et al.* 2009).

[INSERT TABLE 6-5 HERE:
Table 6-5: Examples of Social Protection Measures that bring disaster risk management and climate change adaptation benefits among the poorest in society.]

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6.4.4. Low Carbon Development and Disaster Risk

Carbon-intensive development produces greenhouse gases that contribute to climate change. Continued focus on this type of development will only accelerate the changing of the climate and climate extremes experienced (Yamin et al. 2005) and exacerbate vulnerability. The search for linkages between adaptation and mitigation has been going for many years, yet there are still few examples of the general benefits from addressing climate change adaptation and mitigation jointly as opposed to separately (Klein et al 2007). Few of these examples focus on disaster risk reduction and fewer still are initiated and managed at the national scale. Klein et al (2007) cite the use of air conditioning as a risk reducing strategy in heatwaves; the use of afforestation that stabilizes soils; managing urban heat islands through green roves and trees for shade as examples of joint action on adaptation and mitigation that also aligns with national disaster risk management systems. Proponents of low carbon, climate resilient growth suggest that there are developmental (and hence adaptation) benefits from pursuing domestic emissions reduction policies (Ayres and Huq, 2009). Kok et al. (2008) provide examples of how developmental gains can be made through greenhouse gas emissions reduction. They argue that energy security can be enhanced through hydro-power and suggest that a large scale hydro-power scheme could improve energy supply across southern Africa. Further they highlight the health improvements seen after the switch to biofuelled vehicles in Brazil (Kok et al. 2008).

Low carbon climate resilient development could be an effective strategy for some countries in land use planning, water management and urban planning, although in most cases greater benefits may be found by addressing adaptation and mitigation separately (Swart and Rees, 2007). Swart and Rees (ibid) nonetheless recommend identifying synergies between adaptation and mitigation wherever possible to reduce the need for later trade-offs between the two policies. In South African rangelands drought is a recurrent problem. Restoration of the rangelands could provide enhanced resilience to drought, however the agricultural policy currently in place is unlikely to deliver this, as there are multiple other interests that need to be addressed requiring land reform (Vetter, 2007). Institutional and social barriers to learning and change present a significant hurdle to potential advances in adaptation and mitigation initiatives that generate risk reduction benefits (Dietz et al. 2003). A first step to achieving this is to clearly document the risk reducing benefits from joint action on adaptation and mitigation. Specifically, under what conditions these co-benefits arise, and where national intervention (through for example, education and knowledge transfer, payments or penalties, and regulation) can deliver these co-benefits.

6.4.5. Conclusion: Approaching Disaster Risk, Adaptation, Mitigation, and Development Holistically

Diverse and complex challenges of climate change call for a fundamental shift in how climatic risks are viewed, treated and responded to. Ideally, national systems for managing risks from climate extremes and disasters would need to be redesigned to fully integrate development, environmental and humanitarian dimensions, appropriately designing, coordinating and sequencing disaster risk reduction strategies, including social protection, and climate change adaptation. However no country, developed or developing, could afford to do this in the short term. A second best option would be to progressively move towards such a system by, in the first instance, aligning existing national disaster risk management systems to more frequent and extreme events of higher intensity and uncertainty, as well as by addressing the underlying drivers of vulnerability e.g. poor economic well being and social inequalities

Strategies for mainstreaming climate change into national development planning and budgetary processes, and climate proofing at the sector level were discussed in Sections 6.2 and 6.3. In this section, the focus has been on the system level changes required to address uncertainty, in the form of explicitly assessing economic benefits, net of costs, of options for adaptation to changing risks associated with climate change, adaptive management, and linking poverty reduction and managing risks of climate extremes by focusing on transformative social protection. None of these measures are likely to be easy to implement as actors and stakeholders at all levels of society are being asked to embrace risk as an inherent part of management; and continuously learn and modify policies, decision and actions taking into account new scientific information as they emerge and experiential lessons. A space that is poorly understood and more scientific work is needed to understand human beings perception of risks, their decision-making processes in the face of uncertainty and different stakeholder and human values, and then to translate these knowledges into governance arrangements and incentives for change. Other major transformational ideas such as focussing on low-carbon development strategies producing synergistic outcomes for climate change mitigation and adaptation is unclear. More research and experiments with different low carbon initiatives and their sensitivity to changing disaster risks are needed before firm conclusions can be drawn about their effectiveness.

Given the new information presented in this report, factoring in the impacts of climate change, including the associated changing disaster risks and uncertainties, and the need to tackle the drivers of vulnerability in to disaster risk management systems and finding synergistic climate change adaption and mitigation solutions will remain priorities for most countries.

6.5. Research Priorities

The knowledge-base for the assessment of national systems for managing the risks of climate extremes and disasters, their practices and actors is evolving rapidly as more countries prioritise climate change related risk management within national and sub-national development and planning processes. At the same time, there are significant gaps in our knowledge about the specific ways that climate change is affecting and altering disaster risks and uncertainties (see Chapters 3 and 4) and the associated impacts on the different dimensions of vulnerability and exposure that may exacerbate future disasters. Such uncertainty may be viewed by national level policy actors as a barrier to making policies, adopting legislation and targeting investments in managing disaster risks. However, as this chapter has shown, there is considerable experience of measures to respond to existing climate variability and disaster risk that can reduce the adaptation deficit, be viewed as 'no regrets' and not be dismissed as risking mal-adaptation to a changing climate (see Section 6.3.1.3 for examples). Furthermore, it is important for understanding climate change, its effects on disaster risks and uncertainties, to build adaptive capacity and promote adaptive management and the compulsion to tackle the dual issue of vulnerability and poverty. It is equally important to understand their causes to be progressively integrated into, and used to realign and redesign, national systems for managing the risks of climate extremes and disasters. Experience of this happening and experience of creating national systems that integrate disaster risk, climate adaptation, environmental management and development more broadly is largely missing. In practice for national systems this would mean engaging a wider groups of communities of practice in planning, budgetary, policy design and investment decisions and implementation, connecting legislation and overarching national and subnational committees associated with climate change to disasters and development more explicitly, and assembling robust information, expertise and decision-making systems that can recognise changing patterns of risk and uncertainty and respond accordingly. In order to gain such experience, this chapter has highlighted the following research priorities.

- How wise is the current trend to support decentralisation of disaster risk management functions to regional and local governments given the information requirements, changing risks and associated uncertainties of climate change? To what extent are efforts to build disaster risk management capacities at different scales creating sets of skills that prepare people and organisations for the new challenges that climate change poses (see Section 6.3.2.2)?
- How are the roles and responsibilities of different actors working within national disaster risk management systems changing given the impacts of climate change? To what extent are the traditional functions associated with managing disaster risk being reshaped or redistributed as a result of climate change (see Section 6.2)?
- Are systems that integrate a wider set of communities of practice and line ministries more efficient at reducing disaster risk or adapting to climate change than supporting a series of parallel efforts that place less emphasis on cross-sectoral co-ordination?
- What are the benefits and trade-offs of creating programmes and policies that seek to manage disaster risk, mitigate and adapt to climate change and reduce poverty simultaneously? To what extent do changing climate extremes and disaster risks present limits to low carbon growth? (Swart and Rees 2007, see Section 6.4).
- How to better monitor and demonstrate the successes (and failures) of managing risks due to climate variability and change as a means to provide more incentive for ex ante intervention as compared to the still dominant ex post stance taken for dealing with disasters.

Frequently Asked Questions

1) What constitutes a national system for managing risk associated with climate extremes and disasters *(S 6.1 Introduction)*, and how does it differ from 'national level' of managing risks of climate change related extremes and disasters? (*S. 6.2.1).*
2) What are the respective roles of governments (national and subnational), private sector, communities, and development partners in addressing the risks of climate change related extreme events and disasters? (*S 6.2.1 – 6.2.4).*
3) Under what conditions is the private sector likely to be willing (or not willing) to share in the risks of climate change related extreme events and disasters and assist communities to minimise their burden of disaster management costs? (*S 6.2.2 and S 6.3.3.3).*

4) What can government (national and subnational) policy makers do, domestically, to help reduce risk and manage residual risks of climate change related extremes and disasters?(*S 6.3.1 – 6.3.2; S6.4.1-6.4.5).*
5) How can countries integrate considerations of increasing risks of climate change related extremes and disasters to reduce risks, transfer risks and manage residual risks? (*S 6.3.1-6.3.2; S 6.4.1-6.4.2).*
6) What methods and tools are currently available to help develop a culture of resilience (S 6.3.3.1); reduce climate-related disaster risks though hard and soft options (S 6.3.3.2), and transferring and sharing 'residual risks? (S 6.3.3.3).
7) What is 'Ecosystem based Adaptation' to climate change and what role can it play in providing triple win outcomes? (*S 6.3.3.2.3).*
8) What best practice examples are currently available to demonstrate the value of integrating disaster risk reduction and climate change adaptation in a country? (*S 6.4.1 – 6.4.2).*
9) What is 'adaptation deficit' in relation to current risk management, how will this be affected under climate change? (*S. 6.1.2); and what could be* done to transform current disaster risk management system into a system that addresses 'adaptation def*icit'* and meets the challenges of climate change? (*S 6.3.1-6.3.2 6.4.1-6.4.5).*
10) How can communities and countries become climate smart in an environment of limited baseline information about climate change? (S 6.3.3.1; S6.4.2).

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Table 6-1: National policies, plans, and programs: selection of disaster risk management and adaptation options.

Sector/ Response	**No regret actions**	**Reduce uncertainties** ***('No regrets' options plus…)***	**Reduce climate change risks** ***("Reducing uncertainties" options plus...)***	**Transfer of risks**	**Managing residual risks**	**'Triple win' - GHG reduction, adaptation, risk reduction and development benefits**
Natural Ecosystems and Forestry	▪ Use of Ecosystem-based Adaptation (EbA) or "soft engineering"; Financial recognition of EbA; Integrate DRR and climate into Integrated Coastal Zone and Water Resources Management; forest, land-use Management; Conserve, enhance resilience of ecosystems; restore protective ecosystem services [1] ▪ Adaptive forest management Forest fire management, controlled burns; Agroforestry; biodiversity [2]	▪ Synergies between UNFCCC and Rio Conventions (e.g. UN CBD); avoid perverse incentives in conventions [3] ▪ Research on climate change-ecosystem-forest links; climate and ecosystem prediction systems, climate change projections; Monitor ecosystem and climate trends [3] ▪ Incorporate ecosystem management into NAPAs and DRR plans [3]	▪ CCA interventions to maintain ecosystem resilience; corridors, assisted migrations; Plan EbA for climate change [4] ▪ Seed, genetic banks; new genetics; tree species improvements to maintain ecosystem services in future [4] ▪ Changed timber harvest management, new technologies, new uses to conserve forest ecosystem services [4]	▪ Micro-funding and insurance to compensate for lost livelihoods [5] ▪ Investments in additional insurance, government reserve funds for increased risks due to loss of protective ecosystem services [5]	▪ Replace lost ecosystem services through additional hard engineering, health measures [6] ▪ Restore loss of damaged ecosystems [6] ▪ Reduce forest harvesting and provide incentives for alternate livelihoods [6]	▪ Afforestation reforestation, conservation of forests, wetlands and peatlands, increased biomass; LULUCF; REDD [7] ▪ Incentives, Sequestration of carbon; sustainable bio-energy; energy self – sufficiency [7]
Agriculture and Food Security	▪ Food security via sustainable land and water management, training; Efficient water use, storage; Agro-forestry; Protection shelters, crop and livestock diversification; Improved supply of climate stress tolerant seeds; Integrated pest, disease	▪ Increased agriculture-climate research and development [10] ▪ Research on climate tolerant crops, livestock; Agrobiodiversity for genetics [10] ▪ Integration of climate	▪ Adaptive agricultural practices for new climates, extremes [12] ▪ New and enhanced agricultural weather, climate prediction services [11] ▪ Food emergency planning;	▪ Improved access to crop, livestock and income loss insurance, (e.g. weather derivatives) [13] ▪ Micro-funding and micro-	▪ Changed livelihoods and relocations in regions with climate sensitive practices [12] ▪ Emergency	▪ Energy efficient and carbon sequestering practices; Training; Reduced use of chemical fertilizers [14]

	management [8] ▪ Climate monitoring; Improved weather predictions; Disaster management, crop yield and distribution models and predictions [9]	change scenarios into national agronomic assessments [11] ▪ Diversification of rural economies for sensitive agricultural practices [10]	Distribution and infrastructure networks [12] ▪ Diversify rural economies [12]	insurance [13] ▪ Subsidies, tax credits [13]	stock and improved distribution of food and water [12]	▪ Promote Bio-gas from agri-waste and animal excreta[14] ▪ Agroforestry [14]
Coastal Zone and Fisheries	▪ EbA; Integrated Coastal Zone Management ICZM; Combat salinity; alternate drinking water availability; soft and hard engineering [15] ▪ Strengthen institutional, regulatory and legal instruments; Setbacks [16] ▪ Marine Protected Areas, monitoring fish stocks, alter catch quantities, effort, timing; Salt-tolerant fish species [17] ▪ Climate risk reduction planning; Hazard delineation; Improve weather forecasts, warnings, environmental prediction [16]	▪ CC projections for coastal management planning; Develop modelling capacity for coastal zone-climate links; Climate-linked ecological and resource predictions; Improved monitoring, geographic and other databases for coastal management [18] ▪ Monitor fisheries; Selective breeding for aquaculture, fish genetic stocks; research on saline tolerant crop varieties [19]	▪ Incorporate CCA, sea-level rise into ICZM, coastal defences; [18] ▪ Hard and "soft" engineering for CCA; Resilient vessels and coastal facilities [16] ▪ Manage for changed fisheries, invasives [19] ▪ Inland lakes: Alter transportation and industrial practices, Soft and hard engineering [20]	▪ Enhance insurance for coastal regions and resources; Fisheries insurance [21] ▪ Government reserve funds [21]	▪ Enhance emergency preparedness measures for changed extremes, including evacuations [16] ▪ Relocations of communities, infrastructure [16] ▪ Exit fishing; alternate livelihoods [19]	▪ Promote renewable energy; conservation, energy self-sufficiency (especially for offshore islands, coastal regions) [22] ▪ Offshore renewable energy for alternate incomes and aquaculture habitat [22]
Water resources	▪ Implement Integrated Water Resource Management (IWRM), national water efficiency, storage plans [23] ▪ Effective surveillance, prediction, warning and emergency response systems; Better disease and vector control, detection and prediction systems; better sanitation; Awareness and training on public health [24] ▪ Adequate funding, capacity	▪ Develop prediction, climate projection and early warning systems for flood events and low water flow conditions; Research and downscaling for hydrological basins [24] ▪ Multi-sectoral planning for water; Selective decentralization of	▪ National water policy frameworks, IWRM incorporate CCA [25] ▪ Investments in hard and soft infrastructure considering changed climate; river restoration [25] ▪ Improved weather, climate, hydrology-hydraulics, water	▪ Public-private partnerships; Economics for water allocations beyond basic needs [26] ▪ Mobilize financial resources and capacity for	▪ National preparedness and evacuation plans [24] ▪ Enhanced health infrastructure [24] ▪ Transport, engineering; temporary consumable	▪ Integrated water efficiency and renewable hydro power for CCA [23]

	for resilient water infrastructure and water resource management; Improved institutional arrangements, negotiations for water allocations [23]	water resource management (e.g. catchments and river basins); joint river basin management (e.g. bi-national) [23]	quality forecasts for new conditions [24]	technology and EbA [26] ▪ Insurance for infrastructure	water taking permits [24] ▪ Food , water distribution, alternate livelihoods [24]	
Infra-structure, Housing, Cities, Transportation, energy	▪ Building codes, standards with updated climatic values; Climate resilient infrastructure (and energy) designs; Training, capacity, inspection, enforcement; Monitoring for priority retrofits (e.g. permafrost) [27] ▪ Legal alternatives to shanty settlements, sanitation [27] ▪ Strengthen early warning systems, hazard awareness; Improved weather warning systems; Disaster resilient building components (rooms) in high risk areas; heat-health responses [28] ▪ Integrate urban planning, engineering, maintenance [27] ▪ Redundant, diversified energy systems; Maintenance; Self-sufficiency, clean energy technologies for national energy plans, MEA goals (bio-gas, solar cooker); Promote renewable energy in remote and vulnerable regions; Promote appropriate energy mixes nationally [29]	▪ Improved downscaling of CC information; Maintain climate data networks, update climatic design information; Increased safety/uncertainty factors in codes and standards; Develop CCA tools [28] ▪ Research on climate, energy and built environment interface, including flexible designs, redundancy; Forensic studies of failures (adaptation learning), Improved maintenance [27] ▪ Investments for sustainable energy development; Cooperation on trans-boundary energy supplies (e.g. wind energy at times of peak wind velocity) [29]	▪ Codes, standards for changed extremes; [30] ▪ Publicly funded infrastructure and post-disaster reconstruction to include CCA [30] ▪ New materials, engineering approaches; Flexible use structures; Asset management [30] ▪ Hazard mapping; Zoning and avoidance; Prioritized retrofits, abandon the most vulnerable; Soft engineering services [30] ▪ Design energy generation, distribution systems for CCA; Switch to less risky energy systems, mixes; Embedd sustainable energy in DRR and CCA planning [29]	▪ Infrastructure insurance and financial risk management [29] ▪ Insurance for energy facilities, interruption [29] ▪ Innovative risk sharing instruments [29] ▪ Government reserve funds [29]	▪ Relocation [28] ▪ Evacuation planning; Contingency plan for transport during extreme events [28] ▪ Climate resilient shelter construction [28] ▪ Promote energy security; Distributed energy generation and distribution [29]	▪ Implement energy and water efficient GHG reductions, DRR and adaptation synergies [29] ▪ Scale up, market penetration for renewable energy production; Increased hydroelectric potential; Sustainable biomass; “Greener” distributed community energy systems [29]
Health	▪ Community/urban planning, building standards and guidelines; cooling shelters;	▪ Research on climate-health linkages and CCA options; Develop	▪ New food and water security, distribution systems; air quality	▪ Extend and expand health insurance	▪ National plan for heat and extremes	▪ Promote use of clean renewable

	safe health facilities; Retrofits for vulnerable structures; Health facilities designed using updated climate information [31] ▪ Strengthen surveillance, health preparedness; Early warning weather-climate-health systems, heat alerts and responses; Capacity for response to early warnings; Prioritize disaster risks; Disaster prevention and preparedness; Public education campaigns; Food security [31] ▪ Strengthen disease surveillance and controls; Improve health care services, personal health protection; Improve water treatment/sanitation; Water quality regulations; Vaccinations, drugs, repellants; Development of rapid diagnostic tests [31] ▪ Monitor air and water quality; regulations; urban planning [31]	new health prediction systems for emerging risks; Research on landscape changes, new diseases and climate; Urban weather-health modelling [31] ▪ Education, Disaster prevention and preparedness [31]	regulations, alternate fuels [32] ▪ New warning and response systems; Predict and manage health risks from landscape changes; Target services for most at risk populations [32] ▪ Climate proofing, refurbish/ maintain national health facilities and services; Address needs for additional health facilities and services; Design for climate change; Alternate energy for improved air quality [32]	coverage to include new and changed weather and climate risks [33] ▪ Government reserve funds [33]	emergencies; New disease detection and management systems; Better land and water use management to reduce health risks; Enhanced prediction and warning systems for new risks [32]	energy and water sources; increase energy efficiency; Air quality regulations; Clean energy technologies to reduce harmful air emissions (e.g. cooking stoves) [34]

TABLE 6-1 NOTES:

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[2] FAO, 2007; Neufeldt et al, 2009; Shugart et al, 2003;.Spittlehouse and Stewart 2003, Weih, 2004.

[3] Colls et al, 2009; FAO, 2008a; SCBD, 2009; Rahel and Olden, 2008; Robledo et al, 2005; OECD, 2009; SCBD, 2009; UNEP, 2009; UNFCCC, 2006.

[4] Berry, 2007; FAO, 2007; FAO, 2008a; FAO, 2008b; OECD, 2009; Leslie and McLeod, 2007; SCBD, 2009.

[5] CCCD, 2009; Coll et al, 2009; FAO, 2008b; ProAct, 2008; UNFCCC, 2006.

[6] Chhatre and Agrawal, 2009; FAO, 2008b; Reid and Huq, 2005; SCBD, 2009;

[7] FAO, 2008a; Reid and Huq, 2005; SCBD, 2009; UNEP, 2006; Venter et al, 2009;

[8] Arnell 2004; Branco et al., 2005; Campbell et al, 2008; FAO, 2008a; FAO, 2009; Fischer et al. 2006; Howden et al, 2007; IPCC, 2007; ISDR, 2009; McGray et al, 2007; Neufeldt et al., 2009; Romano, 2003; SCBD, 2009; World Bank, 2009.

[9] FAO, 2007; Hammer et al, 2003; IPCC, 2007; ISDR, 2009; McCarl, 2007; Taggarwal et al, 2006; UNFCCC, 2006; World Bank, 2009.

[10] FAO, 2007; Campbell et al, 2008; CCCD, 2009; IPCC, 2007; World Bank, 2009.

[11] FAO, 2007, IPCC, 2007; World Bank, 2009.

[12] Butler and Oluoch-Kosura, 2006; Butt et al, 2005; CCCD, 2009; Davis, 2004; FAO, 2006; FAO, 2007; FAO, 2008a; Howden et al, 2007; McCarl, 2007; Romano, 2003; World Bank, 2009.

[13] CCCD, 2009; FAO, 2007; IPCC, 2007; ISDR, 2009; World Bank, 2009.

[14] Batima et al. 2005; FAO, 2007; Rosenzweig and Tubiello, 2007.

[15] Adger et al, 2005; Kay and Adler, 2005; Kesavan and Swaminathan, 2006.

[16] Adger et al, 2005; FAO, 2008b ; Kesavan and Swaminathan, 2006; Klein et al, 2001; Nicholls, 2007; UNFCCC, 2006a.

[17] FAO, 2007; FAO 2008b; IPCC, 2007; Rahel and Olden, 2008; UNFCCC, 2006.

[18] Adger et al, 2005; Dolan and Walker, 2003; FAO, 2008b; Nicholls, 2007b; Thorne et al, 2006; UNFCCC, 2006b; World Bank, 2010.

[19] FAO, 2008b; Kesavan and Swaminathan, 2006;Rahel and Olden, 2008.

[20] FAO, 2007; IIED, 2009.

[21] FAO, 2007; Nicholls, 2007.

[22] FAO, 2008b; UNFCCC, 2006a.

[23] Branco et al, 2005; CCCD, 2009; Hedger and Cacourns, 2008; ICHARM, 2009; IPCC, 2007; Klijn et al., 2004; Mills, 2007; Olsen, 2006; Rahaman and Varis, 2005; World Bank, 2009; WSSD, 2002; WWAP, 2009.

[24] Arnell and Delaney, 2006; Auld et al, 2004; CCCD, 2009; DaSilvia et al, 2004; Hedger and Cacouris, 2008; Mills, 2007; Muller, 2007; Thomalla et al., 2006; UNFCCC, 2006b; UNFCCC, 2009; WHO, 2003; World Water Council, 2009; WWAP, 2009.

[25] CCCD, 2009; Crabbe and Robin, 2006; Hedger and Cacourns, 2008; IPCC 2007; Rahaman and Varis, 2005; WWAP, 2009.

[26] Few et al, 2006; Kirshen, 2007; Mills, 2007; Rahaman and Varis, 2005; Warner et al, 2009; WWAP, 2009.

[27] Auld, 2008; Auld, 2008a ; Hodgson and Carter, 1999; IPCC, 2007; Lowe, 2003; Mills, 2007; NRTEE, 2009; ProVention, 2009; Satterthwaite, 2007; Rosetto, 2007; Wamsler, 2004; World Bank, 2000; World Bank, 2008; World Water Council, 2009.

[28] Auld, 2008; Auld, 2008a ; Auld, 2008b; Lewis and Chisholm, 1996; Mills, 2007; Neumann, 2009; ProVention, 2009; Rosetto, 2007; UNFCCC, 2006.

[29] Auld, 2008a ; IPCC, 2007; Islam and Ferdousi, 2007; Kagiannas et al, 2003; Marechal, 2007; Mills, 2007; Neumann, 2009; Robledo er al, 2005; UNDP/WHO, 2009; VanBuskirk, 2006; Warner et al, 2009; Younger et al, 2008.

[30] Auld, 2008a; Freeman and Warner, 2001; Mills, 2007; Neumann, 2009; NRTEE, 2009; ProVention, 2009; Stevens, 2008; Younger et al, 2008.

[31] Auld et al, 2004; Auld, 2008a; CCCD, 2009; Curriero et al, 2001; DaSilvia et al, 2004; Ebi et al, 2006b; Haines et al, 2006; Patz et al, 2000; Patz et al, 2005; UNFCCC, 2006; WHO, 2003; WHO, 2005; WHO, 2008; World Bank, 2003..

[32] CCCD, 2009; Ebi et al, 2006b; Ebi, 2008; Haines et al, 2006; Patz et al, 2005; Younger et al, 2008; UNFCCC, 2006a; WHO, 2003; WHO, 2005.

[33] Mills, 2005; Mills, 2006.

[34] Haines et al, 2006; Younger et al, 2008.

Table 6-2: Government liabilities and disaster risk.

Liabilities	**Direct**: obligation in any event	**Contingent**: obligation if a particular event occurs
Explicit: Government liability recognized by law or contract	Foreign and domestic sovereign borrowing, expenditures by budget law and budget expenditures	States guarantees for non-sovereign borrowing and public and private sector entities, reconstruction of public infrastructure
Implicit : A 'moral' obligation of the government	Future recurrent costs of public investment projects, pensions and health care expenditure	Default of sub-national government as public or private entities provide disaster relief.

Source: Modified after Schick and Brixi, 2004

Table 6-3: Information requirements for selected disaster risk reduction and climate change adaptation activities.

Activities	**Information needs**
Cross-cutting	
Climate change modelling	Time series information on climate variables, air and sea surface temperatures and circulation patterns, green house gas levels, rainfall and precipitation measures.
Hazard zoning and "hot spot" mapping	Inventories of landslide, flood, drought, cyclone occurrence and impacts at district level; human development indicators
Relief payments	Dense network of rain gauges to calculate meteorological drought indices; household surveys of resource access
Seasonal outlooks for preparedness planning	Seasonal climate forecast model; sea surface temperatures; remotely sensed and *in situ* measurements of snow cover/depth, soil moisture, vegetation growth; teleconnection indices; monthly rainfall-runoff; crop yields; epidemiology
Flood risk management	
Early warning systems for fluvial, glacial and tidal hazards	Real-time meteorology and water-level telemetry; rainfall and tidal surge forecasts; remotely sensed snow, ice and lake areas; rainfall-runoff model
Structural and non-structural flood controls	Inventories of pumps, drainage and defence works; land use maps for hazard zoning; post disaster plan; climate change allowances for structures; floodplain elevations
Artificial draining of pro-glacial lakes	Satellite surveys of lake areas and glacier velocities; inventories of lake properties and infrastructure at risk; local hydro-meteorology
Drought management	
Traditional rain and groundwater harvesting, and storage systems	Inventories of system properties including condition, reliable yield, economics, ownership; soil and geological maps of areas suitable for enhanced groundwater recharge; water quality monitoring; evidence of deep-well impacts
Long-range reservoir inflow forecasts	Seasonal climate forecast model; sea surface temperatures; remotely sensed snow cover; in situ snow depths; teleconnection indices; multi-decadal rainfall-runoff series
Water demand management and efficiency measures	Integrated climate and river basin water monitoring; data on existing systems' water use efficiency; metering and survey effectiveness of demand management

Source: Adapted from Wilby (2009)

Table 6-4: Total number of people reported affected, by type of phenomenon and by year (1999 to 2008), in thousands.

Type of disaster/Years	**1999**	**2002**	**2006**	**2008**	**Total**	**Percentages**
Subtotal climato-, hydrometeorological Disasters	*295,236*	*710,524*	*138,586*	*166,606*	*2,606,736*	*96.8*
Subtotal geophysical Disasters	*6,890*	*1,130*	*4,237*	*47,351*	*87,233*	*3.2*
Total natural disasters	**302,126**	**711,654**	**142,823**	**213,957**	**2,693,969**	**100**

Source: Based on IFRC, 2009

Table 6-5: Examples of social protection measures that bring disaster risk management and climate change adaptation benefits among the poorest in society.

SP measure	**SP instruments**	**Adaptation and DRR benefits**
Provision (coping strategies)	– social service protection – basic social transfers (food/cash) – pension schemes – public works programmes	– protection of those most vulnerable to climate risks, with low levels of adaptive capacity
Preventive (coping strategies)	– social transfers – livelihood diversification – weather-indexed crop insurance	– prevents damaging coping strategies as a result of risks to weather-dependent livelihoods
Promotive (building adaptive capacity)	– social transfers – access to credit – asset transfers/protection – starter packs (drought/flood resistant) – access to common property resources – public works programmes	– promotes resilience through livelihood diversification and security to withstand climate related shocks – promotes opportunities arising from climate change
Transformative (building adaptive capacity)	– promotion of minority rights – anti-discrimination campaigns – social funds	– transforms social relations to combat discrimination underlying social and political vulnerability

Chapter 7: Managing the Risks: International Level and Integration Across Scales

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Note to Expert Reviewers

Working over the past 6 months on the First-Order Draft (FOD) of SREX Chapter 7 (Managing the Risks: International Level and Integration Across Scales) has been a learning experience for all the authors. At this time we wish to acknowledge and point out some of what we consider to be the weaknesses in the draft, and specifically request comments and suggestions from you that will help us to improve the Second-Order Draft. We wish to draw your attention to seven points. This is of course without prejudice to any other comments you may wish to make.

1) The FOD is about right for total length as allocated. Additions and expansions can be made but only to the extent that an equal amount of existing text is reduced or deleted.
2) Perhaps our biggest realization has been that this topic as given to us in the IPCC approved outline is very large indeed. We need to find ways and a good rationale for making the chapter more focused, and limiting its scope to the really crucial issues. We would welcome your guidance on how best to do this, and what changes you consider would be most helpful. We are sure that this will entail cutting out some of the text, and perhaps this will be easier when authors review the contents of the other FOD chapters. In addition to suggestions for cutting and focusing we are of course open to proposals for additional material that has so far been overlooking or otherwise omitted. If additional material or topics/issues are suggested we would welcome citation to the additional literature that should be examined.
3) We are conscious of the fact that the chapter does not have a good “flow”. Another way of saying this is that it lacks continuity and integration and a good “storyline”. Comments and suggestions would be welcome.
4) The chapter is too heavy on the description of international management frameworks and institutions, and is lacking in assessment. One reason for this is that there appears to be very little “assessment” literature that is publicly accessible and in peer-reviewed journals, and that there is a very large volume of both descriptive and prescriptive literature. In consequence many of our references are drawn from the grey literature. We are in desperate need of more peer-reviewed literature with a potential for strengthening the “knowledge assessment” content of the chapter. Suggestions and advice are needed and welcome.
5) This latter point applies especially to Sections 7.4, 7.5, and 7.6. We are conscious of weakness in these sections and invite suggestions of ways of strengthening them and suggestion of other quality and/or peer-reviewed literature. In particular we would welcome suggestions of additional material on Section 7.5 (Considerations for Future Policy and Research) and 7.6 (Integration Across Scales).
6) Given the broad nature of the subject matter of Chapter 7 we find that the expertise on our team (while excellent in all respects) falls short of the wide range of expertise on which we need to draw. We are open therefore to the suggestion (or volunteering) of additional “contributing authors”.
7) One idea that is being discussed in relation to some of the above points is to treat the topic of “international level management” in a more evolutionary manner giving attention to the history or time line of the development of institutions and principles. While this would not be strictly evaluative it might perhaps help to create a better sense of understanding of the directions in which management at the international level has been moving for both DRM and CCA. It is not the intention to make this a basis for “policy prescription”, but to help identify future options and opportunities and research needs and knowledge gaps. Reactions welcome.

Contents

Executive Summary

There are compelling reasons and principles of international governance why substantial efforts are required at the international level to reduce weather and climate – related disaster risks and promote across scales adaptation to extreme events associated with climate change.

Two of the main institutional frameworks are the International Strategy for Disaster Reduction (ISDR) and the adaptation elements in the United Nations Framework Convention on Climate Change (UNFCCC). The ISDR and UNFCCC efforts to develop a management approach have been developed largely along separate and independent tracks.

While disaster risk management (DRM) has received considerable attention recently through ISDR and other organizations and institutions, the results in terms of number and size of weather and climate-related disasters including property losses and numbers of people affected has not been encouraging. According to Munich Re data, trends in overall losses and insured losses from great natural catastrophes have continued to increase although fatalities per event have decreased.

Climate change adaptation (CCA) has been prominent on the international agenda for a much shorter period of time than DRM. There are still wide ranging debates how adaptation should be approached in the international area, including its link to overall development. As a result, systems of management and governance of adaptation are still being formulated. On the other, DRM has recently have had to review its strategy in the light of changing patterns of hazards and risks and growing inequalities.

Both DRM and CCA face significant obstacles if they are to advance towards greater success and operational effectiveness in creating less risky and more resilient communities and nations. There are governance and legal obstacles, estimating costs of damages and financial constraints, the availability and distribution of technology and management capacity, and in the means of risk transfer and sharing. In all these cases there are considerable opportunities which could be made available by reducing the existing constraints and by the development of new creative and integrative approaches.

There is a strong prima facie case to be made for bringing DRM and CCA closer together in a more integrated and synergistic approach. They have much to learn from each other. It is also the case that successful DRM and CCA cannot be achieved in isolation from other institutions and management capacities and that much depends on development choices and pathways.

Much might be achieved on the basis of present knowledge and its more effective deployment. At the same time it is clear that many questions remain unanswered and sometimes not asked. Despite the growth in knowledge (or maybe because of it) uncertainty will remain high, and there is a large agenda for future research.

Globalization and the closer integration of the world economy and social interactions of many kinds proceed apace. Changes in finance, communications, trade, patterns of economic growth, (among others) are changing the nature of disaster risk. Continued growth of greenhouse gas emissions means that much better understanding of the processes of adaptation is needed although adaptation will be a solution only up to some extent. This applies at the practical and operational level and at a more fundamental level of theory. Several prominent research needs and directions are identified.

While closer integration between DRM and CCA is needed at the international level, the same applies at the local and national levels where its link to addressing the MDGs and sustainable development are to be realised. Most important for the development of better management of DRM and CCA is the need to integrate and harmonize across scales between local, national and international. To achieve this requires an improvement of both bottom-up and top-down flows of knowledge, finance, technology, institutional frameworks, legal instruments, and the strengthening of mutual trust and confidence.

Literature also shows that existing tools and instruments of international law can assist with disaster risk reduction and management and in driving adaptation to climate change. However, international law is limited in scope and enforceability when applied to addressing these same challenges. The international legal status of instrumental policy frameworks on climate extremes i.e. the UNFCCC, the HFA and the MDGs are not identical and as a result these policy frameworks continue to operate parallel to each other resulting in duplication and sometimes contradicting efforts.

[NOTE: The Executive Summary will also include information on the overarching questions identified in Section 7.1.1 and relevant conclusions.]

7.1. The International Level of Risk Management

This chapter brings together and assesses the knowledge from two domains of expertise: disaster risk reduction (DRR) and climate change adaptation (CCA) at the international level. It seeks to identify the lessons that can be learned from disaster risk reduction (largely in the absence of anthropogenic climate change) and to assess how DRR experience might help to inform and guide the rapidly growing practice of climate change adaptation. Similarly climate change, especially the changing pattern of climate extremes, poses a new challenge for disaster risk management (DRM). The interaction of DRR and CCA applies at all spatial scales and governmental levels of risk management. This chapter also addresses the topic of integration across scales.

7.1.1. Overarching Questions

A first question concerns the rationale for DRM and CCA at the international level. On what grounds are these problems managed partly at the international level? The second question concerns the development of institutions and institutional capacity at the international level. What institutions exist and what capacity do they have? A third question concerns the management constraints and opportunities for DRR and CCA. What exists and what are the possibilities for the future? A fourth question concerns the gaps in knowledge. What is being done and needs to be done about further knowledge creation and its relation to policy needs? The last section of this chapter then turns to the question of integration across scales

As outlined in Section 7.3. the reduction of mortality and morbidity and property losses from weather and climate-related disasters has been a major concern of the international community for some decades at least. The Global Assessment Report on Disaster Risk Reduction (GAR) (2009) acknowledged that climate change is a global driver of disaster risk. GAR (2009) notes that weather-related disaster risk is escalating swiftly both in terms of the regions affected, frequency of events and losses reported and that climate change is changing the geographic distribution of these weather-related hazards, threatening to weaken the resilience of poorer countries, their community's ability to absorb losses and recover from disaster impacts. Although continuous improvement in early warning systems and a number of other international programmes and organizational responses have been highly effective in reducing risks (Global Network, 2009), losses are still significant (see Chapter 4). The following data from Munich Re provide one widely quoted source of information about the losses as estimated in U.S. dollars (see Figure 7-1). While there are many legitimate questions about the accuracy of the data and its interpretation (i.e., that there are variations between years), there is little doubt about the overall trend over time (Goklany 2006; Hoppe and Pielke eds, 2006). These estimates are a gross underestimation of for instance, the role of the cumulative effect of both major and minor events on increasing poverty globally indicating that the long term material and mortality losses linked to disaster is not known.

[INSERT FIGURE 7-1 HERE:
Figure 7-1: Overall and Insured Losses from Great Natural Catastrophes 1950-2006 Source: Munich-Re (2007)

At a global scale the results in terms of mortality and morbidity have been much better, and although the numbers affected by disasters has continued to increase the actually number of fatalities per disaster has declined. Nevertheless developing countries continue to record high mortality and losses relative to their GDPs compared to the developed nations (see Figure 7-2).

[INSERT FIGURE 7-2 HERE:
Figure 7-2: Differential burden of natural disasters according to country income groups. Source: Linnerooth-Bayer, et al., 2010 (based on data from Munich Re, 2005). (Note: country income groups according to World Bank classification)]

Many indicators of disaster losses have worsened in recent years, despite rapidly expanding scientific knowledge about the risks, increased global interconnectivity and flow of information and major international efforts in DRM. Climate change is expected to increase hazards, and all other things being equal, human and economic losses (see Chapters 3 and 4 and Section 7.4). This leads to the question "why in a period of rapidly expanding scientific knowledge about the risks, increased global interconnectivity and flow of information and major international efforts in DRR have losses continued to increase?" (White, Kates, and Burton. 2001). Similarly it should be asked what might be done at the international level to prevent losses rising even more rapidly in an era of climate change, and how climate change adaptation might be promoted, supported and implemented in such a way that disaster losses are reduced or at least the rate of increase is lowered. Could it possibly be that the knowledge and experience of DRR when combined with CCA and linked to development could in fact achieve more positive results that either seem to be achieving at present?

It is important to enter the qualification that not all DRM elates to climate change and not all CCA relates to disasters. For example a major concern of the DRM community is with earthquakes, tsunamis and other geophysical, conflicts and technological events that are not generally related to climate change. Similarly the CCA community has to be concerned with the slow incremental consequences of climate change such as sea level rise and the expansion of the arid regions and the pace of desertification. Despite the different time scales involved the risks are not entirely unrelated. If drought events increase in severity or duration (or both) as seems likely with climate change in some places (Chapters 3 and 4) then periodic and intermittent drought disasters may be slowly transformed into a permanent and ongoing challenge for adaptation, either in situ or by relocation. Similarly tropical cyclones may become more severe as sea level rises and as ocean surfaces become warmer (Chapter 3).

Chapters 5 and 6 have addressed these questions by examining the reported strengths and achievements of local communities and national governments while Chapter 8 examines the linkages between DRR and development. In this chapter, we turn to examining responsibility at the international scale and their effectiveness in managing climate extremes. Two caveats are in order. First there is an intentional focus on disaster risk management as a governmental function. The public sector is the main focus of negotiation and regulation of international response and management. Less attention is given to the private sector; to the individual or the household; and to humanitarian non-governmental organizations. For example in the private sector, the Global Disaster Resource Network is a global network of companies in the engineering, construction, logistics and transportation sectors that are committed to assisting humanitarian organisations resources free of charge. Dunfee and Hess (2000) have shown that the private sector has a comparative advantage in humanitarian efforts through their business culture for instance in high levels of efficiency, lower cases of corruption due to their vulnerability to competitive pressure. The private sector also has a role in long term disaster risk management for instance microcredit arrangements and education sponsorships. At all three governmental levels however the questions are addressed – where is the boundary between public (governmental) and private sector action and responsibility, and similarly between government and the private citizen or household, and non-governmental or civil society organizations? These questions raise the issue of greater focus on creating partnership at various levels between the different government entities (Warhurst, 2005).

The second caveat concerns the simple division into local, national, and global. There are other levels of government and governance. Often the villages and communities at lowest level of “governance” are grouped into larger regions. Then there are major cities and metropolitan regions. In states and countries with large territories and federal constitutions there are also “state”, “provincial” or other sub-national levels of government. Beyond the strictly national level there are many kinds of bilateral and multilateral arrangements, formal and informal, for the management of trans-boundary risks, or for the management of shared ecosystems or river basins (Linnerooth-Bayer et al, 2001). “International” does not necessarily mean global, but there is a global dimension. Climate change and its associated extremes constitute a set of risks that are clearly global if only in the sense that all of humanity is being or will be impacted by changes in the climate system and the global atmosphere. The earth’s atmosphere is the ultimate common property resource cutting across all scales.

7.1.2. Elements of Management

This chapter addresses the overarching questions in sequence. First the main elements of and principles that are used to justify international response are described in Section 7.2. This discussion provides the existing rationale for action at the international level. It is shown that this has evolved from a largely humanitarian approach towards consideration of principles and ethics. The need for international action has also increased with the greater integration of the world economy (globalization and systemic risks), and with the world-wide impacts of climate change which raise dangers of major economic inefficiency, and growth in inequity. The UNFCCC itself has moved the debate increasingly in the direction of international law, to the point of considering the nature of international responsibilities and obligations.

Secondly the chapter describes and assesses the current international governance and institutions (Section 7.3) for DRM and CAA. There is now a rich mosaic of frameworks and organizations including not only those specifically directed towards CCA and DRM, but also many other components of the international governance system. Climate change is a globally pervasive phenomenon in which all human institutions are to some degree involved. Section 7.4 addresses the third issue; that of constraints that hinder the development of more effective DRM and the implementation of effective CCA practices. Section 7.4 also identifies opportunities in expanded financing, technology development, and risk sharing and transfer, including various forms of insurance. The questions of knowledge generation and sharing for DRM and CCA are also addressed.

7.1.3. Potential to Reduce Exposure and Vulnerability at the International Level

Although climate extremes have a negative effect they help to raise consciousness of climate change within the public and policymakers. This can then provide further legitimacy to governmental action in terms of supporting DRM, enhancing adaptation and promoting mitigation (Adger et al., 2005). An international framework for integration of climate related disaster risk management and CCA in the development process could provide the potential for reducing exposure and vulnerability (Thomalla et al., 2006; Venton P. and Trobe, 2008). Collective efforts at the international level to reduce greenhouse gases are a way to reduce long-term exposure to frequent and more intense climate extremes. International frameworks designed to facilitate adaptation with a deliberate effort to address issues of equity, technology transfer, globalisation and the need to meet MDGs can when combined with mitigation lead to reduced vulnerability (Haines et al., 2006; Adger et al., 2005). The 2007/2008 Human Development Report noted that if climate change is not adequately addressed now 40 per cent of the world’s poorest i.e. 2.6 billion people - will be confined to a future of diminished opportunity (Stern, 2006). The long term potential to reducing exposure to climate risks lies in sustainable development (O’Brien et al, 2008)

7.1.4. The Role of DRM and CCA at the International Level in Building a Sustainable and Resilient Future

Adaptation is defined as “an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC, 2001) while DRR is defined as “the broad development and application of policies, strategies and practices to minimise vulnerabilities and disaster risks throughout society, through prevention, mitigation and preparedness” (UN ISDR, 2007). Although each extends beyond the scope of the other both seek to build resilience through sustainable development (O’Brien et al., 2008). This supports the need for DRM to be a key component in the ongoing UNFCCC climate negotiations as recognised in the Bali Action Plan (BAP). (UNFCCC – Bali Action Plan COP 13 2007) Disaster risk management could be realised through increased awareness and understanding of synergies and differences in CCA and DRR, and by providing a framework for integration in areas of overlap between the two (Venton P.and Trobe, 2008). The World Conference on Disaster Reduction (WCDR) held in Kobe, Japan in 2005 and the BAP point to the need for incorporation of measures that reduce climate change disasters with in DRR. Integration of the relevant aspects of DRR and CCA can be facilitated by using the Hyogo Framework for Action (HFA) 2005–20152 agreed by 168 governments in Kobe, Hyogo, Japan in 2005. International support in terms of for example institutional changes and pilot projects focusing on systematic integration of disaster risk management and climate change adaptation care other mechanisms of facilitating a move towards building of resilient societies.

7.1.5. Other Related International Activities

Anthropogenic climate change is a globally pervasive phenomenon, affecting all sectors of human society, including the economic, financial and social dimensions. Climate change also affects managed and unmanaged ecosystems. It is not therefore a public policy issue which can be cordoned off and left to a small number of specific and dedicated organizations and agencies to manage. The operations of all UN Specialized Agencies and many other international bodies are likely to be impacted by climate change in varying degrees, and the operations of all are also subject to extreme events and disasters. It is beyond the scope of this chapter and this report to address in any detail all these other related international activities. A select few are described in Section 7.3.4 to illustrate the scope of international involvement.

7.2. Rationale for International Action

The pattern of responsibilities for DRM and CCA at the local, national and international scales has evolved over time as the nature and magnitude of the risks have changed, as the capabilities of the various levels of governance have also changed, and as the architecture of international governance has been constructed over recent decades. Nevertheless it is possible to discern guiding elements and principles that have been used to guide and justify, as well as constrain, the allocation of responsibilities.

This section examines these guiding elements and principles as they have been articulated and applied for DRM and CCA, and codified into international practice and international law. This report focus mainly on the international level of human organization and governance and describes principles of subsidiarity, solidarity, and efficiency, as well as the reality of dependent and systemic risks, as they have shaped international discourse, practices and legal frameworks.

7.2.1. Subsidiarity

Subsidiarity is based on the concept that decisions of government (other things being equal) are best made and implemented, if possible, at the lowest most decentralized level closest to the citizen. While the principle of subsidiarity can be traced back to the Treaty of Rome (1957), it was specifically articulated in Article 5 of the Treaty of Maastricht on European Union in 1992 (The Maastricht Treaty, 1992). The intent of multi-level governance is thus that the centralized governing structure should only take action if deemed more effective or necessary or otherwise than action at a lower level; it requires cooperation between all levels of government (Jordan, 2000). Subsidiarity is designed to strengthen accountability and reduce the dangers of making decisions in places remote from their point of application. The principle does not necessarily limit or constrain the action of higher orders of government, it merely counsels against the unnecessary assumption of responsibilities at a higher level (Begg, 2008). In the case of the risk management of climate extremes, major weather and climate events such as tropical cyclones, large floods and droughts can quickly overwhelm the capacity of local governments to respond. Weather events also frequently affect more than one community, resulting in the need for national level response. This commonly applies especially to the poorest and least developed nations.

Subsidiarity also recognizes the importance of harmonizing actions in an integrated way across governing levels. For example, in 2004 the African Union (AU) developed a continental wide African Regional Strategy for Disaster Risk Reduction (African Union, 2004). Below the continental level, disaster management strategies are being developed at the regional level (e.g., under the Regional Economic Communities), national level (e.g., National Disaster Management platforms), district level (e.g. District Disaster Management Committees) and local levels (e.g., Village Development Committees). Action at any one level can affect all others in a reflexive fashion. These interactions can both enhance or constrain coping and risk management. While many regions and river basins, for instance, are required to develop risk management flood plans, flood protection is predominantly a national (and in many countries, e.g., Germany and India), a state responsibility. The principle implies that international or national level involvement should only apply to cross-border catchment areas (Stoiber, 2006). Disaster and climate financing in terms of subsidiarity means that matters should be managed by the lowest level that demonstrates relevant competency (Craeynest, et al., 2010); however, the evaluation of the competency may be assumed at a higher level. Ideally, the principle of subsidiarity should be used as a tool to protect against infringing on local level intervention or support (Gupta and Grubb, 2000).

Also according to the principle, national level strategies for disaster management and adaptation plans should be developed with the participation of regional or local level decision makers. This active engagement at all levels is necessary to help identify the most suitable measures for proper governance and implementation.

7.2.2. Solidarity

When the management or coping capacity of lower levels of government is exceeded then higher levels can be involved on the basis of a formal or informal social contract. This applies especially to post-disaster response. Our common humanity leads people to care for each other especially in times of crisis or adversity. The rapid expansion of global communications in the latter half of the 20th Century has enabled many more people to receive reports and see pictures of disaster scenes everywhere in the world. There has been a corresponding growth in per capita voluntary contributions to humanitarian assistance in disaster situations. National governments as part of their governing mandate come to the aid of communities and sub-national levels. Nations cooperate and help each other when their individual capacities are stretched or exceeded. And at the global level, voluntary actions and multilateral agreements are created to facilitate the identification, planning and execution of modes of mutual assistance, and in some cases to propose or mandate the allocation of responsibilities. Recently, the principle of solidarity underlying post-disaster humanitarian assistance has been extended to providing assistance for pre-disaster interventions that reduce and transfer risk (Kreimer and Arnold, 2000).

With growing globalisation the principle of solidarity is further enhanced as offers of e.g. disaster relief may provide nations access to new spheres of influence both politically and in terms of new business opportunities. Nations can piggyback a humanitarian effort on top of a for-profit operation involving their companies (Dunfee and Hess 2000).

7.2.2.1. Common Humanity

Values that define our common humanity have been most cogently expressed through the eight Millennium Development Goals (MDGs), which respond to the world's main development challenges. The MDGs are drawn from the actions and targets contained in the Millennium Declaration that was adopted by 189 nations-and signed by 147 heads of state and governments during the UN Millennium Summit in September 2000. In the words of the Declaration:

> *We recognize that, in addition to our separate responsibilities to our individual societies, we have a collective responsibility to uphold the principles of human dignity, equality and equity at the global level. …Global challenges must be managed in a way that distributes the costs and burdens fairly in accordance with basic principles of equity and social justice. Those who suffer or who benefit least deserve help from those who benefit most.* (UNGA, 2000)

Based on this declaration of global solidarity, climate-related risks are part of the "collective responsibility" referred to in the Declaration because poor countries suffer the most in terms of development and human well-being. In the poorest countries, people are four times more likely to die due to natural disasters, and the cost per disaster as a share of GDP is much higher than in OECD countries (Barnett et al, 2008). Between 1991 and 2001 there were 1,052 deaths per disaster in countries with low human development indexes (HDI) compared to only 23 for high HDI countries. Moreover, increasing frequency, magnitude and spatial coverage of climate extremes (see Chapter 3) mean losses are fast exceeding the capability of many individual countries to manage the risk (Rodriguez et al, 2009). It is well established across a large literature that the most vulnerable countries will have difficulty in adapting to extreme events and other impacts of climate change without significant international assistance (World Bank, 2010; Klein and Persson, 2008; Klein and Mohner 2009; Agrawala and Fankhauser 2008; Agrawala and van Aalst, 2008; Gupta et al., 2010).

Weather extremes constrain progress towards meeting the MDGs , especially the goal of eradicating extreme poverty and hunger (UNDP, 2002; Mirza, 2003; HDR 2007/2008, 2007; UN ISDR, 2009a), which can be interpreted as a direct raison d'être for international intervention in risk management (UN ISDR, 2005b; Heltberg et al, 2008). Barrett et al. (2008) have shown that the poor's ex ante risk management strategies commonly tradeoff expected gains such as investing in fertilizers or improved seed to reduce risk of suffering catastrophic loss, a situation perpetuating the "poverty trap". The poor are frequently subjected to double or multiple exposure from climate change and other stesses like geophysical hazards and changing economic conditions (e.g., fluctuating exchange rates) leading to vulnerability to even moderate hazard events (O'Brien and Leichenko, 2000).

Common human concern has been articulated most effectively with regard to post-disaster humanitarian assistance, and the Millennium Declaration gives specific mention to natural disasters in this context. Humanitarian assistance, although essential for upholding this principle, can lead to emphasizing disaster response strategies at the expense of pro-active integrated approaches to disaster risk reduction (UNDP, 2002). This can have the effect of perpetuating vulnerability (Bhatt, 2007). For this reason, the DRM and CCA communities are placing great emphasis on pre-disaster investment and planning to redress this balance and reduce overall costs of disaster management (Kreimer and Arnold, 2000; Linnerooth-Bayer et al., 2005).

7.2.2.2. Principled Responsibility

Beyond a sense of common human concern, and expressions of solidarity in the MGDs it has been pointed out that countries contributing most to climate change have a “principled” obligation to support those who are most vulnerable and who have had limited contribution to the problem. This is the claim underlying the notion of Common but Differentiated Responsibility (CBDR), which has emerged as a principle of international environmental law and has been explicitly formulated in the context of the 1992 Rio Earth Summit.

> "In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command." [Principle 7, the Rio Declaration]

The CBDR informs in particular the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, but mainly with respect to mitigation. The CBDR can be said, in synthesis, to express the need to evaluate responsibility for the remediation or mitigation of environmental degradation based on both historical contribution to a given environmental problem and present capabilities: it is a guiding principle of international cooperation and solidarity (De Lucia, 2007).

The CBDR is anchored in a large literature from law and political science on environmental justice, which examines principles for responsibility for international action and focuses on identifying fairness within such principles. Some of this literature examines principles for compensation as a result of imposed harm. Farber (2007, 2008), Delink et al. (2009) and Grasso (2010) review potential arguments over who is responsible and who should pay for adaptation. Farber (2007) suggests that potential principles for allocation of responsibility include: a) compensation by the beneficiaries of the adaptation and that if benefits are localized, there is no justification for international transfer; b) by governments through an international taxation on the basis of ability to pay; c) by polluters, in this case those who emit greenhouse gases and hence ultimately cause the harm; or d) by those who are ‘climate change winners’ (rather than be harmed) from the impacts of climate change. These principles have received some attention in diverse literatures. Farber (2007) dismisses principle d) as the likely winners from climate change are not widespread and concludes that having emitters pay for adaptation (in effect the polluter pays principle) has greatest normative appeal, but also suggests significant benefits and feasibility of global compensation and risk spreading.

Another set of literature suggests that adaptation to human-induced climate change is categorically different to previous adaptation to risk in that it involves the avoidance of harm imposed by others (e.g. Caney, 2010; Adger et al. 2009). Caney (2008) makes the case that equity issues around climate change can be framed as the right ‘not to suffer from dangerous climate change’ (p. 537) or as ‘rights to avoid dangerous climate change’ (Adger, 2004). Climate change impacts jeopardise fundamental interests of individuals in their life and livelihoods (such as impacts on disease burden, malnutrition and food security): rights to life, health and subsistence as a minimum set. Caney (2010) also discusses a right ‘not to be forcibly evicted’ (p. 83) as a potential further undeniable right. This literature suggests that fundamental interests are significant enough, and universal enough to warrant obligations on others, even without recourse to the polluters pays principle. As Caney points out, this strong case for rights in this area are amplified if consideration is given to both future generations and the natural world. The framing of climate change as a set of rights raises a number of difficult issues in their implementation and in seeking to balance between competing fundamental rights (O’Brien et al., 2009). This argument applies to climate change in general including incremental change, but can be taken to apply to climate related disasters where there is evidence or reason to believe that the disaster would not have occurred or would have been less severe in the absence of climate change (see Section 3.3).

7.2.3. Systemic Risks

Risks from extreme events can be far reaching. Large regions including groups of several countries may be directly affected by climate-related hazards. For example, between 2006 and 2007 two consecutive positive Indian Ocean Dipole (pIOD) events caused far-reaching climate and societal impacts in regions and countries, including: Australia, where exceptionally long lasting droughts were experienced; East Asia and South India, where floods resulted in high mortality; Indonesia, which experienced unprecedented wildfires; and Europe, which experienced dry and warm anomalies (Luo et al., 2008). Moreover, the risks are not independent from each other but co-variant, which means that their management may require risk reduction and risk sharing mechanisms that reach across borders. For example, if insurers with limited capital reserves choose to indemnify large co-variant and recurring risks, they must guard against insolvency by diversifying their portfolios geographically, limiting exposure and/or transferring their risks to the global reinsurance and financial markets (Mechler and Linnerooth-Bayer, 2006). Major interlinked events, such as global sea level rise, will bring not only increased levels of hazard to specific areas, but the initial impacts of such changes can extend to second and third order impacts with world wide and systemic effects. This can apply to the contiguous zones of many countries, such as shared basins with associated flood risks, which calls for trans-boundary, international mechanisms. The impacts can also be felt globally through impacts on international trade and human relocation and migration.

The term “systemic risk” refers to risks that are characterized by linkages and interdependencies in a system, where the failure of a single entity or cluster of entities can cause cascading impacts on other interlinked entities. Climate-related disaster risks can be systemic as the impacts of a less direct nature cascade beyond the immediate region affected. Relationships and connections involving the movement of goods (trade), finance (capital flows and remittances), and people (displaced populations) can extend to continents and indeed to the world as a whole Normally, in the past, the amplification of such events beyond the region in which the disaster occurs has been minimal and short lived, essentially because the global economic system has been sufficiently loosely coupled to absorb major shocks that have occurred without significant ripple effects. Because of greatly increased international inter-dependency, shocks occurring in one country can potentially have major and bi-directional systemic impacts on other parts of the world (Kleindorfer, 2009), although the extent of these impacts is not well documented. Chastened by the unexpected systemic cascading of the 2007-2008 financial crisis, firms with global supply chains are now devoting significant resources to crisis management and disruption risk management (Sheffi, 2005; Harrington and O’Connor, 2009).

Disaster events can also result in the temporary or permanent displacement of hundreds or thousands or more people sometimes across international borders. As opposed to abrupt displacement due to extreme weather events, mobility and migration can also be an adaptation strategy (Barnett and Webber, 2009) , although the very poor and vulnerable will in many cases be unable to move (Tacoli, 2009). Evidence on the extent of current and future disaster- and climate-change induced migration is debated (Myers, 2005; Morrissey, 2009; Guzman, 2009). It is difficult to disentangle the drivers of migration, including climate change risks, rising poverty, urbanization, spread of infectious diseases such as HIV/AIDS, and conflict (Thomalla et al., 2006; Barnett, and Adger 2007; CIENS, 2007). To the extent that weather extremes contribute to migration, it can result in a huge burden to the destination areas where the capacity of the area to provide essential services may be threatened, the potential for disease transmission heightened and when combined with loss of social support systems the process may deepen poverty and increase further vulnerability to even usually low risk weather events (Heltberg et al, 2008; Morrissey, 2009; Warner et al., 2009). The impact of climate -driven migration on human security including violent conflict, international trade and the overall global economy is not known and continues to be a source of concern prompting the need for international intervention (Barnett and Adger, 2007; Heltberg et al., 2008;Warner et al., 2009; Tacoli, 2009).

7.2.4. Economic Efficiency

The public policy literature sets out principles by which governments should intervene to assist both their citizens and those outside their national jurisdictions to adapt to climate change impacts. Stern (2007), for example, makes the case that adaptation will not happen autonomously because of missing and misaligned markets ((p. 467), and that international transfers are justified on the basis of the principles of interdependence of the world economy (discussed above) and the public good nature of many risk management interventions, for example, implementing regional warning systems and collecting climate data. Tompkins and Adger (2005), Berkhout (2007) and others discuss how some areas, such as water resources, change from being public to private depending on national regulations and circumstances, thereby questioning the strength of the public good principle for adaptation. Nevertheless, the principles of interdependence and public goods suggested by Stern and others are widely adopted and shared within the literature on international responsibility (Vernon, 2008; World Bank, 2010; Gupta et al., 2010).

In addition to the public good nature of many adaptation measures, there are also economic efficiency grounds for international cooperation. Early warning systems, as an example, may be conceived as nationally based, but many warning systems depend on regional and international cooperation to secure the exchange of necessary data. This is not straightforward, however, as sovereign states can view their data as having strategic or commercial value, and for these reasons can deny or limit its exchange. In the field of meteorology, many years of discussion under the auspices of the World Meteorological Organization (WMO) have led to formal agreements on the types of data that are routinely exchanged (WMO 1995). Much remains to be done to achieve similar levels of agreement in other hazard fields (Basher, 2006).

Another example of economic efficiency justifying the management of risks at an international level is regional risk pooling. By pooling risks across individual countries, regions, and the world, catastrophe insurance pools generate diversification benefits that are reflected in reduced insurance premiums (see Section 7.4).

7.2.5. Legal Obligations and Responsibilities

7.2.5.1. Scope of International Law, Managing Risks and Adaptation

The intersections between climate change damage and international law have assessed in details by Verheyen 2004. Contemporary international law concerns the coexistence of States in times of war and of peace (19th century conception of international law, rooted in the Westphalian system), the relationship between a State and citizens (e.g. human rights law), and the cooperation between States and other international actors in order to achieve common goals and address common concerns (e.g. international environmental law). International law, according to the authoritative article 38 of the Statute of the International Court of Justice, emanates from three primary sources: (1) international conventions, which establish “rules expressly recognised by the … states”, and result from a deliberate process of negotiations; (2) international custom, “as evidence of a general practice accepted as law”; and (3) general principles of law, “recognised by civilized nations”. This triumvirate of conventional and customary international law, and general principles of law, contain legal norms and obligations which can be used to motivate, justify and facilitate international cooperation on climate change adaptation, such as contained within the UNFCCC, and in anticipation of and response to natural disasters, such as with the emerging field of international disaster relief law.

In addition to international sources of “hard law”, international norms exist in the form of non-legal resolutions, guidelines, and codes of conduct (Bodansky 2010; Chinkin 1989). Collectively these international legal and non-legal instruments provide a framework within which States have obligations and commitments of relevance to adapting to climate change and disaster risk management. These include obligations to mitigate the effects of desertification (United Nations Convention to Combat Desertification), to formulate and implement measures to facilitate adaptation (United Nations Framework Convention on Climate Change), to exercise precaution (Rio Declaration), and for international cooperation to protect and promote human rights (Office of the High Commissioner, 2009 (para 84 *et seq.*)).

At the same time as international law appears to provide a normative framework and to impose obligations that mandate reducing and managing risk and helping adaptation to climate change, the literature also suggests that international legal instruments on their own are ill-equipped to live up to the challenge. To illustrate, the law of international disaster response, which establishes a legal framework for transborder disaster relief and recovery, has been characterised as "dispersed, with gaps of scope, geographic coverage and precision" (Fisher 2007), with states being "hesitant to negotiate and accept far-reaching treaties that impose legally binding responsibilities with respect to disaster preparedness, protection, and response" (Fidler 2005). International refugee law for its part does not recognise environmental factors as grounds for granting refugee status to those displaced across borders as a direct result of environmental factors (Kibreab 1997).

7.2.5.2. International Conventions

Few internationally negotiated treaties deal directly with managing risk associated with climate extremes or with adaptation to climate change.

The UNFCCC obligates Parties to facilitate adequate adaptation, to cooperate with planning for extreme weather, and to consider international insurance schemes. Specifically at article 4.1(b), Parties to the UNFCCC agree to "Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing… measures to facilitate adequate adaptation to climate change." At .1(e), Parties agree to "Cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods." Linnerooth-Bayer and Mechler (2006) observe that support for insurance instruments as means of climate risk management is increasing. Article 4.8 of the UNFCCC requires Parties to consider actions, including insurance, to meet the specific needs and concerns of developing countries. And at article 3.14, UNFCCC's Kyoto Protocol calls specifically for the establishment of insurance.

In addition to the UNFCCC, Parties to the UNCCD aim to "combat desertification and mitigate the effects of drought in countries experiencing serious drought and/or desertification… through effective action at all levels, supported by international cooperation and partnership arrangements…" (Article 2).

The Tampere Convention on the Provision of Telecommunication Resources for Disaster Mitigation and Relief Operations is the only contemporary multilateral treaty on the topic of disaster relief (Fidler 2005). Aiming to reduce regulatory barriers for important equipment for disaster response and entered into force in 2005, the Tampere Convention's first application has been met with limited success (Fisher 2007).

7.2.5.3. Customary Law and General Principles

Customary law and general principles, unlike international conventions, emerge from informal processes and do not exist in canonical form (Bodansky 2010 (p. 192 *et seq*)), though customs and principles are often reflected in international treaties. This is the reality of various customs and principles that justify or mandate international action on disaster risk reduction and climate change adaptation. To be considered part of customary law, a process is generally regarded as requiring two elements: continuous state practice (regular behaviour), and a sense of legal obligation (*opinio juris*) (Bodansky 1995-96). General principles of law, by contrast, are not customary norms and do not reflect behavioural regularities. They are rather an articulation of collective aspiration, important in shaping the "development of international law and negotiations to develop more precise norms" (Bodansky 2010 (p. 200)). In practice, the distinction between rules of customary law (reflecting actual practice of states), and general principles, is frequently blurred. For instance, the principle of common but differentiated responsibilities – which would for example suggest that states have differentiated responsibilities in addressing disaster risk and financing adaptation – is increasingly supported by state practice, however *opinion juris* is lacking with respect to which states consider the principle to be a legal obligation. The principle of common but differentiated responsibilities might thus fall closer to a general principle than customary norm. Irrespective of this status, CBDR is nevertheless available to states in articulating their respective responsibilities under international law.

The precautionary principle states that scientific uncertainty does not justify inaction with respect to environment risks (Trouwbrst 2002), and is articulated in a number of international treaties including article 3 of the UNFCCC. That states have a duty to prevent trans-boundary harm, provide notice of and undertake consultations with respect to such potential harms is another norm expressed under international environmental law. The more general duty to cooperate has evolved as a result of the inapplicability of the law of state responsibility to problems of multilateral concern, such as global environmental challenges. The Office of the High Commissioner for Human Rights has noted that "Climate change can only be effectively addressed through cooperation of all members of the international community" (OHCHR 2009). From the duty to cooperate is deduced a duty to notify other states of potential environmental harm. This is reflected in Principle 18 of the Rio Declaration (a non-legal international instrument), that "States shall immediately inform other States of any natural disasters or other emergencies that are likely to produce sudden harmful effects on the environment."

7.2.5.4. Non-binding Legal Instruments

Many international instruments are non-legal in nature (Raustiala, 2005), as is the case with respect to disaster relief where many of the most significant international instruments are non-binding. The Code of Conduct for the International Red Cross and Red Crescent Movement and Non-Governmental Organsiations in Disaster Relief (1995) and the Sphere Project Humanitarian and Minimum Standards in Disaster Response (2004) focus on the quality of relief developed by the international humanitarian community, though are limited by lack of a compliance mechanism (Fisher in *Tsunamis*…). The Guiding Principles on Internal Displacement (UN Doc. No. E/CN.4/1998/52/Add.2 1998) articulates principles of indirectly related to disaster prevention and of human vulnerability (Fisher 2007).

International human rights norms as articulated in International Bill of Human Rights have also been applied to disaster risk reduction and adaptation to climate change. Notably the Report of the Office of the High Commission for Human Rights observes that climate change and response measures thereto have generally a negative effect on the realisation of human rights including rights to life, adequate food, water, health, adequate housing and self determination (OHCHR 2009). These rights risk being jeopardised when contemplated, for example, in context of migration induced by extreme weather events. As discussed in Section. 7.3.1 The Hyogo Framework for Action further stipulates key tasks for governments and multi-stakeholder actors, among these the development legal frameworks. It is an international framework, a priority area of which is to ensure that disaster risk reduction is a national priority with an institutional basis for implementation. As to adaptation, the Bali Action Plan agreed to at UNFCCC COP 13 recognises the need for disaster risk reduction strategies and risk management within adaptation (FCCC/CP/2007/6/Add.1).

7.3. Current International Governance and Institutions

7.3.1. Hyogo Framework for Action (HFA)

7.3.1.1. Description of HFA

In 1989, the United Nations General Assembly adopted a resolution that designated the1990s as the International Decade for Natural Disaster Reduction (IDNDR), demonstrating a commitment to disaster reduction. This was the first major collective international attempt to reduce disaster impact, particularly within hazard-prone developing countries (Wisner et al 2003 pp 323-325). Each country was encouraged to establish national committees, and over 120 were established. In 1994, the first proposal for disaster reduction was developed during the Yokohama Conference on Risk Reduction termed the Yokohama Strategy and Plan of Action, providing policy guidance with technical and scientific basis. In 2000, the IDNDR was followed by the United Nations International Strategy for Disaster Reduction (UN ISDR), which broadened the scope to include increased public commitment and linkages to sustainable development. The approach of the ISDR system has been to promote the use and scaling up of tools and methods to reduce disaster risk while additionally encouraging the collaboration between disaster reduction and climate change by, for example, developing disaster risk reduction and adaptation planning and programming. Partners in the ISDR system engage in capacity-building for climate change and disaster risk reduction actions, awareness-raising at community and national levels, advocacy with climate change delegates to promote the integration of the disaster risk reduction approach in international climate policy, and the production and dissemination of risk assessment and management tools. The ISDR secretariat provides information and guidance on disaster risk reduction to manage climate risks and adapt to climate change, both to inform international policy deliberations and to assist governments and other parties to reduce climate-related vulnerabilities and risk. It undertakes global reviews of disaster risk and progress on risk reduction and facilitates the compilation, exchange, analysis and dissemination of good practices and lessons learned in disaster risk reduction. In January 2005, 168 governments supported the Hyogo Framework for Action (HFA) 2005-2015: Building the Resilience of Nations and Communities to Disasters at the United Nations World Conference on Disaster Reduction in Kobe, Japan (WCDR). The Framework was unanimously endorsed by the UN General Assembly (UN ISDR, 2005a).

The HFA's Strategic Goals include the integration of DRR into sustainable development policies and planning; development and strengthening of institutions, mechanisms and capacities to build resilience to hazards; and the systematic incorporation of risk reduction approaches into the design and implementation of emergency preparedness, response and recovery programmes (UN ISDR, 2005a). The Framework also provides five areas of Priorities for Action:

1) Ensure that DRR is a national and local priority, with a strong institutional basis for implementation
2) Identify, assess and monitor disaster risks and enhance early warning
3) Use knowledge, innovation and education to build a culture of safety and resilience at all levels
4) Reduce the underlying risk factors
5) Strengthen disaster preparedness for effective response at all levels.

Note that the priorities do not specify the need to factor climate change risks and adaptation into ongoing action, but the HFA does identify 'critical tasks' for varied actors , including States who are to "Promote the integration of DRR with climate variability and climate change into DRR strategies and adaptation to climate change" (UN ISDR 2005a).

7.3.1.2. Key Actors in HFA

Institutionally, ISDR is designed to create a system of partnerships composed of range of stakeholders with essential roles in supporting nations and communities to reduce disaster risk. These partners include governments, inter-governmental and non-governmental organizations, international financial institutions, scientific and technical bodies and specialized networks as well as civil society and the private sector. Among the diverse range of stakeholders, the national governments play the most important roles for HFA implementation and are responsible for developing national coordination mechanisms; conducting baseline assessments on the status of disaster risk reduction; publishing and updating summaries of national programmes; reviewing national progress towards achieving the objectives and priorities of the Hyogo Framework; working to implement relevant international legal instruments; and integrating disaster risk reduction with climate change strategies. Intergovernmental organizations are expected to promote programmes for disaster risk reduction; undertake and publish regional and sub-regional baseline assessments; coordinate reviews on progress toward implementing the Hyogo Framework within the region; establish regional collaborative centres; and support the development of regional early warning mechanisms. International organizations are intended to encourage integration of disaster risk reduction into humanitarian and sustainable development programmes and frameworks; strengthen the capacity of the United Nations system to assist disaster-prone developing countries with disaster risk reduction initiatives; support data collection and forecasting, information exchange, and early warning systems; supporting countries own efforts with coordinated international assistance; and, strengthen disaster management training and capacity building (UN ISDR, 2005b).

The UN ISDR Secretariat supports and assists the ISDR system in implementing the Hyogo Framework for Action.It is responsible for facilitating the coordination of actions at the international and regional levels; developing indicators of progress to assist States in tracking their progress towards implementation of the Hyogo Framework; supporting national platforms and coordination mechanisms; stimulating the exchange of best practices and lessons learned; and, preparing reviews on progress toward achieving the Hyogo Framework objectives. (UN ISDR, 2009c).

7.3.1.3. Status of HFA

As a result of the adoption of the HFA, global efforts to address DRR have become more systematic. In 2009, the first biennial Global Assessment Report on Disaster Risk Reduction (GAR) was released. The report found that since the adoption of the HFA, progress towards decreasing disaster risk is varied. This variation is based on national agencies self-assessment of progress against the indicators defined in the HFA and hence are not directly comparable across countries. Countries have been making improvements towards increasing capacity, developing institutional systems and legislation to combat DRR; and early warning systems have been implemented in many areas. However, progress is still required to mainstream DRR into planning and development. The GAR findings continued to state that current DRR governance arrangements do not allow for the full integration of risk reduction into development. Further, at national and international levels, policy and institutional frameworks for climate change adaptation and poverty reduction are faintly connected to those for DRR. Underlying risk factors - including poverty, ecosystem decline, poor governance systems and vulnerable livelihoods - are difficult but possible for countries to address using an assortment of mechanisms (e.g., micro-insurance) to increase resilience (UN ISDR, 2009a).

It was also acknowledged in the report that weather-related disaster risk is escalating swiftly both in terms of the regions affected, frequency of events and losses reported. Furthermore, climate change is changing the geographic distribution, intensity and frequency of these weather-related hazards, threatening to weaken the resilience of poorer countries, their communities' abilities to absorb losses and recover from disaster impacts. Climate change is therefore a global driver of disaster risk (UN ISDR, 2009b).

In 2009, the Global Network of Civil Society Organisations for Disaster Reduction also released a report on the performance of the HFA; evaluating the progress on each of the five Priorities for Action (PFA) (GNCSODR 2009). The lowest level of progress across all the five PFA's was in community participation in decision making on DRR. These findings also indicate the need for a shift from policy formulation at international and national levels to policy execution at local levels. Rapid progress has been made in the development of comprehensive seasonal and long-term early warning systems (EWS) to anticipate droughts, floods and tropical storms. These systems have proved to be effective in saving lives and protecting property. A key finding concerned the importance of education and sharing knowledge, including indigenous and traditional knowledge, and ensuring easy and systematic access to best practice tools and international standards, tailored to specific sectors. Civil society grass roots organisations report that climate change is providing the opportunity to address underlying risk factors, raise external resources and political commitment for building resilience. There is some recognition of the benefits in harmonising and linking the frameworks and policies for DRM and CCA as core policy and programmatic objectives in national development plans and in support of poverty reduction strategies. DRM policies could also need to take account of climate change. Ecosystem management approaches can provide multiple benefits, including risk reduction and thus be a central part of such strategies. The policy and institutional frameworks for climate change and poverty reduction are only weakly connected to those for disaster risk reduction, at both the national and international levels. Countries have difficulty addressing underlying risk drivers such as poor urban and local governance, vulnerable rural livelihoods and ecosystem decline in a way that leads to a reduction in the risk of damages and economic loss. Countries are making significant progress in strengthening capacities, institutional systems and legislation to address deficiencies in disaster preparedness and response (Global Network of Civil Society Organisations for Disaster Reduction, 2009; UN ISDR, 2009a).

7.3.2. United Nations Framework Convention on Climate Change (UNFCCC)

7.3.2.1. Description of UNFCCC

The UN Framework Convention on Climate Change (UNFCCC) is an intergovernmental treaty developed to address climate change. The rules, institutions and procedures have been described in details (Yamin and Depledge 2004) The Convention was negotiated from February 1991 to May 1992, and opended for signature at the June 1992 Rio Earth Summit (UN Conference on Environment and Development). Under the Convention, governments collect and share information on GHG emissions, national policies and best practices; launch national strategies for addressing GHG emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries; and cooperate in preparing for adaptation to the impacts of climate change.

Article 2 (the Objective of the Convention) states:

> "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

The Principles of the Convention are outlined in *Article 3*. In their actions to achieve the objective of the Convention and to implement its provisions, the Parties shall be guided, inter alia, by the following:

1) The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.
2) The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration.
3) The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.
4) The Parties have a right to, and should, promote sustainable development. Policies and measures to protect the climate system against human-induced change should be appropriate for the specific conditions of each Party and should be integrated with national development programmes, taking into account that economic development is essential for adopting measures to address climate change.
5) The Parties should cooperate to promote a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, particularly developing country Parties, thus enabling them better to address the problems of climate change. Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.

Adaptation is specifically addressed in four places in the UNFCCC (Article 4.1b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change; (Article 4.1e) Cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods; (Article 4.1f) Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change; (Article 4.4) The developed country Parties and other developed Parties included in Annex II shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects.

In addition Article 4.8 states that "In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing country Parties".

7.3.2.2. Key Actors in Adaptation under UNFCCC

The Convention divides countries into groups according to differing commitments: Annex I Parties include the those developed countries that in 1992 were members of the Organisation for Economic Co-operation and Development (OECD) and is extended to include countries with economies in transition (termed the EIT Parties). Annex II Parties exclude EIT Parties and consist only of the OECD members of Annex I. Non-Annex I Parties are mostly developing countries. Specifically, Annex II Parties are required by the Convention to provide financial resources to enable developing countries to carry out activities that reduce GHG emissions reduction and to assist them in adapting to the impacts of climate change. Additionally, Annex II Parties must advocate the development and transfer of environmentally friendly technologies to EIT Parties and developing countries. Select developing countries are recognized as being particularly vulnerable to the adverse effects of climate change; these include countries with low-lying coastal areas (Tuvalu) and those prone to desertification and drought (areas in Africa). Currently, 49 Parties are classified as least developed countries (LDCs) and given special priority under the Convention (UNFCCC 2009a).

Two key institutions engaged in climate change adaptation at the international level are IPCC, especially Working Group II (WG-II) and the Global Environment Facility (GEF):

- *IPCC Working Group II*: In 1988, an Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) with the objective to assess the scientific, technical and socio-economic information relevant for the understanding of human induced climate change, its potential impacts and options for mitigation and adaptation. So far, four full assessment reports at interval of 3 to 7 years from 1995, guidelines and methodologies and a series of special and technical report have been completed by IPCC. Among the three working groups established by IPCC, Working Group II covers impacts, adaptation and vulnerability Working Group-II engages a group of scientists and experts, from diverse disciplines and regions, for systematic assessment of the scientific, technical, environmental, economic and social aspects of the vulnerability (sensitivity and adaptability) to climate change of, and the negative and positive consequences for, ecological systems, socio-economic sectors and human health, with an emphasis on regional sectoral and cross-sectoral issues.
- Global Environment Facility (GEF): The Global Environment Facility (GEF) is an independent financial organization established in 1991 and provides grants to developing countries and countries with economies in transition for projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants. It has become the largest funder of projects to address global environmental challenges and it serves as financial mechanism for following conventions:
  - Convention on Biological Diversity (CBD)
  - United Nations Framework Convention on Climate Change (UNFCCC)
  - Stockholm Convention on Persistent Organic Pollutants (POPs)
  - UN Convention to Combat Desertification (UNCCD)

> The GEF administers the main international funds that have been made available under the UNFCCC for adaptation - The Special Climate Change Fund, and the Least Developed Countries Fund. Ten international agencies (UNDP, UNEP, World Bank, FAO, IADB, UNIDO, IFAD, and the World, African and Asian Development Banks, EBRD), implement GEF projects, usually in partnership with national or other international agencies.

7.3.2.3. Status of Climate Change Adaptation (CCA) under UNFCCC

The Conference of the Parties (COP) holds annual meetings to assess their progress towards meeting their Convention requirements. COP is the "supreme body" of the Convention, the highest decision-making authority and is responsible for negotiating international efforts to address climate change. The first COP occurred in 1995 in Berlin, Germany; it set the stage for the negotiations on the future Kyoto Protocol. In 1997, during COP 3 in Kyoto Japan the terms of the agreement were established (legally binding reductions in GHG emissions of 6-8% below 1990 levels by 2012) and would enter into force as a legally-binding agreement on the 16th of February 2005. By August 2009, the Protocol was ratified by 189 out of 191countries (the excluding countries are Somalia and the United States of America). In 2007 at COP 13, the Bali Action Plan was adopted (Decision 1/CP.13). The Plan includes adaptation as one of the 4 pillars of the agreement. During that meeting the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA) was also established to conduct the negotiations. In December 2009, COP 15 (Copenhagen, Denmark) did not lead to a legally binding agreement as planned. Negotiations will continue in Cancun, Mexico during COP 16.

In 2001, the Adaptation Fund (AF) was established under the Kyoto Protocol and operationalized during COP13. The AF was created to finance on-the-ground adaptation projects and programmes in developing countries. The Fund is financed by a 2% levy on Clean Development Mechanism (CDM) projects and by voluntary donor contributions. Currently, an Adaptation Fund Board of 16 members and 16 alternates manage the AF, meeting biannually.

To support the least developing countries (LDCs) preparation and implementation of National Adaptation Programmes of Action (NAPAs), the Least Developed Countries Fund (LDCF) was established at COP-7. The fund is operated by the Global Environment Facility (GEF), and gives priority to adaptation. As of February 2010, the GEF has mobilized voluntary contributions of $194 million for the LDCF; 48 of 50 eligible LDCs have received a total of $10.6 million in support to prepare their NAPAs; and 36 NAPA implementation project proposals have been approved and had the necessary funding reserved (countries are allowed to submit more than one implementation project). A round total of $131 million has been approved (i.e. disbursed, committed, or allocated) for the implementation of concrete adaptation action in 33 LDCs (Denmark Ministry of Foreign Affairs 2009, GEF 2010).

7.3.3. Comparative Analysis : International Governance and Institutions

7.3.3.1. International Frameworks and Strategies to Manage Risks

Table 7-1 compares the International Frameworks and Typical Strategies that are adopted to reduce risks. To simplify matters, the Strategies for Reducing Risks have been split into three sections: ‘Structural’, ‘Non-Structural’ and ‘Risk Sharing’. Broadly, a structural measure is one that is a *tangible entity*, such as a flood protection measure, while a non-structural measure may describe an *approach*, such as legislation, a training course etc. However, such tidy divisions may not apply to certain strategies, such as an Early Warning System that will normally comprise structural elements, (such as buildings/ instrumentation/ communications) as well as non-structural measures (such as a community evacuation plan).

[INSERT TABLE 7-1 HERE:
Table 7-1: International frameworks and typical strategies to manage risks.]

7.3.3.2. Actors in the International Policy Frameworks

Table 7-2 lists typical actors who play key roles in Disaster Risk and Climate Change as well as within other International Frameworks.

[INSERT TABLE 7-2 HERE:
Table 7-2: International frameworks and typical actors who manage risks.]

7.3.4. Selected Other Relevant International Policy Frameworks and Agencies

The objectives of climate change adaptation and disaster risk reduction, outlined above are cross-cutting with a wider range of governance and institutional mandates. Similarly, both gradual climate change and extreme weather events, impact on, and are mediated by, other determinants of human vulnerability, such as levels and distribution of natural and economic resources, and the capacities of specific sectors.

It is important to recognize that actions taken outside of the specific DRM and CCA frameworks, for example to enhance economic growth or sustainable development, are likely to have at least as much of an influence on vulnerability to extreme events and the gradual effects of climate change. Rather than attempting an exhaustive review, this section describes the main international effort to promote international development (achievement of the Millennium Development Goals), and selected examples of more specific frameworks that are relevant to DRM and CCA.

7.3.4.1. Millennium Development Goals

Population and ecosystem vulnerability to weather extremes is strongly conditioned by socio-economic development, including income levels and distribution, and supportive institutional frameworks. In addition, the effects of climate change, including through any increase in the frequency of extreme weather events, can also set back economic development (Stern, 2006). Countries that are relatively poor, isolated, and reliant on a narrow range of economic activities are particularly vulnerable to such shocks (UN ISDR, 2009a).

In 2000 the Millennium Declaration identified a series of eight Millennium Development Goals (MDGs), which all members of the United Nations as well as 23 international organisations agreed to achieve by 2015. The eight MDGs break down into 21 quantifiable targets that are measured by 60 indicators.

- MDG 1: Eradicate extreme poverty and hunger
- MDG 2: Achieve universal primary education
- MDG 3: Promote gender equality and empower women
- MDG 4: Reduce child mortality
- MDG 5: Improve maternal health
- MDG 6: Combat HIV/AIDS, malaria and other diseases
- MDG 7: Ensure environmental sustainability
- MDG 8: Develop a Global Partnership for Development.

Sustainable development and progress towards attaining the MDGs are also important elements for integrating adaptation into national plans and programmes, as are risk management and risk reduction policies and poverty alleviation programmes. The target date of the Hyogo Framework for Action was synchronized with the intended completion of the Millennium Development Goals (MDGs) by 2015. The MDGs relate to disasters in two ways: First, if disasters occur they can set back general progress in achieving these goals. Second, the goals connect with specific aspects of disaster risk reduction and climate change adaptation in the manner shown in Table 7-3.

[INSERT TABLE 7-3 HERE:
Table 7-3: Linkages of MDGs to DRM and CCA.]

7.3.4.2. International Trade Frameworks

International trade frameworks affect overall economic development, including rates and equity of poverty alleviation, a key determinant of resilience and adaptive capacity. They also affect transfer of technologies necessary for DRM and CCA. The rules of trade between nations are mainly governed through the World Trade Organization (WTO), which produces accords governing trade in agriculture, services, industrial goods and other matters related to the global economy. The WTO is considering the challenges of climate change. In the Marrakesh Agreement establishing the World Trade Organization, members States established a clear link between sustainable development and disciplined trade liberalization in order to ensure that market opening goes hand in hand with environmental and social objectives. In the current round of negotiations, the Doha Round, members went further in their pledge to pursue a sustainable development path by launching the first multilateral trade and environment negotiations (WTO-UNEP, 2009). A number of aspects of the Doha Round have a direct bearing on sustainable development and can therefore contribute positively to efforts to adapt to climate change. The countries vulnerable to climate change, particularly the LDCs are reported to face constrains by the current international regime of technology transfer. Preferential access to technologies and know-how pertaining to adaptation has remained a crucial challenge for LDC countries to effectively deal with climate extremes (UNCTAD, 2009).

7.3.4.3. Global Health Frameworks

Global health frameworks can help to contain the international spread of diseases that can potentially result from extreme weather events. In response to the exponential increase in international travel and trade, and emergence and re-emergence of international disease threats and other health risks, 194 countries across the globe have agreed to implement the legally binding International Health Regulations (IHR, 2005). These aim to enhance national, regional and global public health security. Key milestones for countries include the assessment of their surveillance and response capacities by June 2009 and the development and implementation of plans of action to ensure that these core capacities are functioning by 2012. The stated purpose and scope of the IHR are "to prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade." Because the IHR are not limited to specific diseases, but are applicable to health risks, irrespective of their origin or source, they will follow the evolution of diseases and the factors affecting their emergence and transmission. The IHR also require States to strengthen core surveillance and response capacities at the primary, intermediate and national level, as well as at designated international ports, airports and ground crossings.

7.3.4.4. International Standards

International standards are defined for a range of practices and materials relevant to DRM. The International Organization for Standardization (ISO) is composed of representatives from various national standards organizations, and has the ability to set standards that are often incorporated into international law. Objectives include – to assist the environmental integrity of GHG assertions, assist organizations to manage GHG related opportunities and risks**.** International Standards practical tools for addressing climate change. ISO standards offer practical tools for addressing climate change at four levels.

1) Monitoring climate change (FAO/WMO)
2) Quantifying GHG emissions and communication on environmental impacts
3) Promoting good practice in environmental management and design
4) Opening world markets for energy efficient technologies.

While most of these tools relate to climate change in general and mitigation in particular, there are many aspects of ISO standards that are relevant to DRM and CCA. One of these is a new ISO 31000 standard on risk management. This strengthens the conceptual and methodological basis for managing human, environmental and economic risks from hazards, including providing a common language among multi-disciplinary actors and combining prevention, preparedness, response and recovery measures. ISO standards also address specific aspects of vulnerability to extremes, particularly the range of ISO standards for insulation, thermal comfort and structural safety in buildings. They also cover specific hazards during disasters. For example, IWA 6, *Guidelines for the management of drinking water utilities under crisis condition*.

7.3.4.5. World Meteorological Organization

The WMO Disaster Risk Reduction Programme aims to ensure the optimization of its global infrastructure and the integration of its core scientific capabilities and expertise into all relevant phases of disaster risk management at the international, regional and national levels, particularly related to risk assessment and early warning systems. WMO and NMHSs have the capability to develop and deliver critical products and services to the entire disaster risk management decision process. These include the multidisciplinary science to understand the vulnerability of communities to weather-, climate- and water related hazards and hazards information for planning of emergency response and disaster mitigation/prevention. These systems operate alongside educational and capacity-building services that help ensure that nations can better meet national needs for hazard information. The DPM’s strategic goals are being realized through an action plan implemented through national and regional projects involving WMO programmes, technical commissions, regional associations and partner organizations that assist member States in strengthening their capacities in disaster risk reduction.

7.3.4.6. The Red Cross and Red Crescent Code of Conduct

The Red Cross / Red Crescent Climate Centre is the reference centre on climate change of the Red Cross / Red Crescent family. The Climate Centre supports the Red Cross and Red Crescent movement to understand and address the humanitarian consequences of climate change and extreme weather events. The Centre's main approach is to raise awareness; advocate for climate adaptation and disaster risk reduction (within and outside the Red Cross and Red Crescent); analyse relevant forecast information on all timescales and integrate knowledge of climate risks into Red Cross Red Crescent strategies, plans and activities.

In 1994, the *Code of Conduct in Disaster Relief* was developed by the Red Cross and Red Crescent. By 2010, 446 organisations had signed the code. The principle commitments by the Red Cross and Red Crescent Movement at the 2007 International Conference are as follows:

1) The Humanitarian imperative comes first.
2) Aid is given regardless of the race, creed or nationality of the recipients and without adverse distinction of any kind. Aid priorities are calculated on the basis of need alone.
3) Aid will not be used to further a particular political or religious standpoint.
4) We shall endeavour not to act as instruments of government foreign policy.
5) We shall respect culture and custom.
6) We shall attempt to build disaster response on local capacities.
7) Ways shall be found to involve programme beneficiaries in the management of relief aid.
8) Relief aid must strive to reduce future vulnerabilities to disaster as well as meeting basic needs.
9) We hold ourselves accountable to both those we seek to assist and those from whom we accept resources.
10) In our information, publicity and advertising activities, we shall recognise disaster victims as dignified human beings, not hopeless objects.

The urgency of addressing the humanitarian consequences of climate change is evident and actions to address these risks need to be ambitious. As reflected in the declaration “together for humanity” the movement has committed to:

- Raise awareness on climate change
- Provide humanitarian assistance
- Improve capacity to respond, including through better disaster preparedness
- Decrease vulnerability of communities most strongly affected
- Integrate climate risk management into policies and plans
- Mobilise human and financial resources, giving priority to actions for the most vulnerable people.

7.3.4.7. Global Facility for Disaster Reduction and Recovery 2006-2015

The Global Facility for Disaster Reduction and Recovery (GFDRR) is a partnership of the International Strategy for Disaster Reduction (ISDR) system to support the implementation of the Hyogo Framework for Action (HFA). The GFDRR is managed by the World Bank on behalf of the participating donor partners and other partnering stakeholders. The GFDRR provides technical and financial assistance to high risk low- and middle-income countries to mainstream disaster reduction in national development strategies and plans to achieve the Millennium Development Goals (MDGs).

GFDRR works to foster and strengthen global and regional cooperation among low- and middle-income country governments, international financial institutions, UN agencies, research and academic institutions, intergovernmental organizations, civil society organizations, and the private sector to leverage country systems and programs in disaster reduction and recovery. It supports development of new tools, practical approaches and financing instruments for disaster reduction and recovery; fosters an enabling environment at the country level that can generate greater investment in disaster risk reduction practices within a sustainable legal, policy, financial and regulatory framework; facilitates knowledge sharing about reducing disaster risks and sustainable disaster recovery; and creates adaptive capacities for limiting the impact of climate change.

7.4. Options, Constraints, and Opportunities for DRM and CCA at the International Level

7.4.1. International Law

As demonstrated in Section 7.2.5, existing tools and instruments of international law can assist with disaster risk reduction and management and in driving adaptation to climate change recognising at the same time that international law is limited in scope and enforceability when applied to addressing these challenges.

7.4.1.1. Limits of International Law (Constraints)

Structurally, international law is both facilitated and constrained by the need for explicit or implicit acceptance by nation states, which create and comprise the system. It follows that the relevance of negotiated treaties depends on state consent, while customary law must be substantiated by state practice and *opinio juris*. For instance, in the case of the Tampere Convention on the Provision of Telecommunication Resources for Disaster Mitigation and Relief Operations noted in s. 7.2.5, only four of the twenty-five most disaster-prone states have signed up, limiting is relevance to many of the states that would most benefit from its provisions (Fisher 2007). International human rights instruments, which at face value are highly relevant to disaster risk response and in supporting an obligation to assist with adapting to climate change, do not enjoy universal acceptance. Furthermore, because international law is made by and applicable to states, the many non-state actors relevant to disaster risk reduction and climate change adaptation are not subject to obligation – though as citizens they may benefit from the duty of states.

Some fields of international law provide tools that seem applicable to disaster risk management and/or adaptation to climate change, yet are constrained through inherent limited applicability. International humanitarian law (IHL) enshrined in the 1949 Geneva Conventions enjoys wide applicability due to universally adhesion (Lavoyer 2006), but is limited to situations of armed conflict. In contrast, the international disaster response law, sometimes proposed as a peacetime counterpart to IHL, not only lacks the central regime and universal adhesion of the Geneva Conventions, but further suffers from entering into force and from problems with coordination and monitoring (Fisher 2007). As a second example, international law has been described as "not yet equipped to respond adequately to the diverse causes of climate-induced migration" (Von Doussa et al 2007). Indeed, international refugee law as codified in the 1951 Convention relating to the Statue of Refugees has been rejected in application to those who cross international borders due to climate-induced migration. Reopening the Convention to expand the term "refugee", it is argued, would risk a renegotiation of the Convention and thus potentially result in lower levels of protection for the displaced (Kolmannskog and Myrstad 2009).

7.4.1.2. Opportunities for the Application of International Law

The potential expansion of the concepts, definitions and procedures known to international law can also be seen as potential future opportunities for international law to address the challenges of disaster risk reduction and adaptation to climate change.

Beyond the international law conventions, custom and principles which already announce the duty of states to mitigate the effects of climate change, facilitate disaster response, and mandate international facilitation of adaptation efforts (see Section 7.2.5), the fact that international law is shaped by nation states and evolves with state practice means that international law may also adapt to future realities. Expanded the interpretation and application of existing international law, and the introduction of new law for disaster response and climate change adaptation are both submitted as plausible in the future.

A candidate field for expanded interpretation is international refugee law. The extant definition of "refugee" is any person who, "for a well-founded fear of being persecuted" will not repatriate. The literature proposes the expansion of "persecution" to encompass being subject to environmental disaster or degradation (Warnock 2007; Kolmmanskog and Myrstad 2009). Comparably, article 7 the International Covenant on Civil and Political Rights prohibits torture and "cruel, inhuman, or degrading punishment". The literature notes the potential expansion of the meaning "degrading treatment" to include being left without basic levels of subsistence to the climate change impacts. A step further proposes a new international agreement to share the "emerging burden of climate-induced migration flows" and which "upholds the human rights of the individuals affected" (Von Doussa et al, 2007).

The emerging legal doctrine of "responsibility to protect" has also been proposed in application to natural disasters. The emergence of state practices in observing certain responsibilities "before, during and after natural disasters occur" in the absence of obligations to do so supports an emerging responsibility to protect in context of natural disaster, and sources human rights law are to be used in promoting this doctrine (Saecho, 2006-2007).

7.4.2. Projected Costs of Climate-Induced Extreme Events

7.4.2.1. The Cost of Climate Change

Available literature that quantifies the global cost of all climate change induced extreme events is scant. The principal challenge in assigning a cost of climate change induced extreme events is of attribution and detection of both the occurrence of, and damage from extreme events as a result of climate change. Another challenge is ensuring that the damages from climate change induced extreme events are examined not on current populations and economies, but on how future scenarios will affect future economies and people. Damages depend critically upon what is in harms' way, not just on the frequency and intensity of the events themselves. For example, the increase in damages from tropical cyclones over the last century in the United States can largely be explained by the increase in capital and people in the path of tropical cyclones (Pielke et al 2008).

While still in its infancy, there have been some recent advances in the literature that attempt to isolate and disentangle the damage of climate change induced extreme events, while controlling for other factors that affect exposure and vulnerability. The literature on tropical cyclone damages is more advanced than for other extreme events. It should be noted however, quantifying impacts or physical damages is, at best, a weak proxy for the "expected cost" of climate change: damages are one measure of the costs of extreme events. But that is different from the measuring of the "costs of managing events", which would depend on the range and type of interventions, and for which there are no existing global estimates.

7.4.2.2. Expected Global Damage from Tropical Cyclones

Climate change could increase future damages from extreme events (IPCC 2007a; IPCC 2007b), with earlier studies estimating global annual damages from tropical cyclones of $630 million (Pearce et al, 1996). Recently, several published papers report an increase in tropical cyclone intensity over the last 30 years (Emanuel 2005, IPCC 2007a), and some reporting increases in tropical storm damages over time (Swiss Re, 2006). The link between climate change and tropical cyclone damage remains controversial, however. Partly this is due to the fact that tropical cyclones are rare events and so it is difficult to detect changes in underlying frequencies and severity (Landsea et al., 2006).

The most recent study to quantify the damage of climate change on tropical cyclones estimates future expected damages as a result of climate change by 2100 to be between $28 and $68 billion dollars (Mendelsohn et al, 2010). These estimates are highly sensitive to assumptions made, and it should be emphasized that substantial uncertainty accompanies these projections, and these projections measure just direct damages. The study also finds that climate change is expected to skew the damage distribution of tropical cyclones and is likely to cause rare - but very powerful tropical cyclones - to become more common and destructive.

7.4.2.3. Expected Global Damages from Other Extreme Events

The literature on expected global damages from other extreme events is scant. Studies use trend analysis to extrapolate hazard damages in the future, arguing that future damages from all extreme events would be between 0.5 to 1 percent of GWP by 2050 (Stern, 2007). However, there are serious flaws in these trend analyses because they confuse the effects of changes in income and population with changes caused by climate change (Pielke, 2007).

7.4.2.4. Summary

There is increasing evidence that climate change will amplify damages by affecting the frequency, intensity, and location of hazards. For many events, notably tropical cyclones, large and rare storms are expected to cause a high fraction of the total damages. All estimates presented above are uncertain, and levels of uncertainty prevail at all levels – from the science to how damages are calculated.

7.4.3. Financing: Incentives, Disincentives, and Implications

Negotiations on financing for adaptation in the developing countries have remained prominent since adaptation was emphasized within UNFCCC process in Marrakesh during COP-7. The Bali Action Plan (BAP) has triggered actions that emphasised the need for international financing to support adaptation in the climate vulnerable developing and least developed countries (GEF 2008). All parties are actively engaged to ensure that the governance of international financing mechanisms becomes transparent, equitable in representation and possess clear lines of accountability (UNFCCC, 2007). Uncertainty still pervades the evolving governance process at the international level. The magnitude and timing of climate change impacts is uncertain and this uncertainty carries over into estimates of adaptation costs. However, it has become apparent that the scale of financing needed to meet the adaptation challenge is significant (GLCA, 2009). Several international organisations have made calculations of the cost of adaptation in developing countries, albeit based on rough assumptions and inconsistent timelines (shown in Table 7-4).

[INSERT TABLE 7-4 HERE:
Table 7-4: Annual adaptation costs in developing countries.]

Current International financing for adaptation is provided in a few dedicated funds through the Global Environment Facility (GEF) under the United Nations Framework Convention on Climate Change (UNFCCC) as well as through development assistance from bilateral and multilateral aid agencies. These funds are mostly designed to support the developing countries for raising awareness, building capacity, advancing understanding of risks and response options, and engaging developing country governments in prioritizing and assessing options (UNFCCC 2009a). Despite world leaders' rhetoric that financing is crucial for effective adaptation; the actual disbursements through these funds have so far been small in relation to estimated needs and only $0.9 billion has been disbursed against total pledge of nearly 18 billion by developed countries (Michell et al 2008).

The GEF manages the Least Developed Country Fund (LDCF), the Special Climate Change Fund and the Strategic Priority on Adaptation (SPA). There have been concerns about the effectiveness of current delivery mechanisms, and the control of funds. Procedural complexities, high transaction cost and unusual delays are reported as the major operational barriers for effective functioning of these funds (Klein and Persson, 2008). It has been argued that the GEF is yet to prioritize the adaptation needs of the most vulnerable and has disproportionately funded projects in countries that have relatively low rates of poverty (Mohner and Klein 2007). Developing countries characterise GEF governance as complex, time-consuming, bias to donor countries and lack of transparency (Michell et al. 2008). Instead of programmatic approach, the emphasis has been on supporting projects (Denmark Ministry of Foreign Affairs 2009; GEF 2005).

The decision for financing modalities at the international level was greatly influenced by the rich donor countries in the past (Burton et al, 2006). Creation of innovative and new financing institutions was opposed by the OECD DAC Countries and, as an existing institution involved in environmental funding, GEF was identified as the preferred funding vehicle for adaptation (Klein and Persson 2008). It is commonly argued that donors resisted instituting a new regime of a kind that they feared would obligate new funds and may complicate the existing international aid system. Donors instead preferred to retain control of funding and urged the agencies to address gap issues through improved coordination (Suhrke and Ofstad, 2005). However in the current negotiations, many parties mostly from the developing world, have expressed their preferences for governance of adaptation funding within the ambit of the convention such as the Adaptation Fund and that funding should be adequate and predictable (Klein and Persson 2008).

The present humanitarian financing at the international level may, in some cases, discourage proactive risk management of climate extremes and catastrophic events. Greater predictability of emergency relief and humanitarian assistance at the international level can help to create a false sense of security for many disaster vulnerable poor countries and due to this scarcity of resources, funding for adaptation to prepare for climate extremes and catastrophic events can be discouraged if countries can expect aid during crises (Hoff et al, 2005). Assistance for adaptation at the international level could be governed in a manner that promotes 5 key principles of Paris Declaration for Aid Effectiveness endorsed by the ministers, heads of aid agencies and senior officials representing some 60 partner countries and more than 50 multilateral and bilateral development institutions. These include: (a) national ownership, (b) alignment with national priorities, (c) harmonisation through simplified and common procedures and shared analysis, (d) managing for results and finally and most importantly (e) mutual accountability.

Many cast climate change as a social justice issue (Michell et al, 2008) and international financing mechanism for adaptation could therefore channel resources effectively to those countries most in need. As many of the impacts will be at the local level, innovative strategies and techniques are needed to support local level initiatives and partnerships, including direct local level access to disaster risk reduction and climate adaptation trust funds and technical resources (GSCSODR, 2009).

To be effective, delivery mechanisms for climate change adaptation and disaster risk reduction are best when flexible and tailored to specific needs and contexts. Concerns have been raised by many donor countries that fiduciary risks in some countries must be managed through improved accountability and transparency before programme based adaptation to take place with international assistance (Michell et al 2009). Many developing and least developed countries require international assistance to build capacity and strengthen institutions for scaling up adaptation efforts (GEF 2008). Strong monitoring and evaluation structure are a crucial part of effective governance, of learning and of promoting efficiency and accountability in programme delivery mechanisms.

Concerns have been voiced whether the concurrent global financial crisis might reduce the priority for climate change adaptation and create another layer of barriers in resource mobilisation for adaptation at the international level. Experience has shown that hundreds of billions, even trillions, of dollars of public funds can be mobilized in a very short period in order to stimulate economic growth and protect against recession. This has strengthened the argument that, if the world leaders are truly committed, there should not be much difficulty in mobilising international assistance to support climate change adaptation which requires in the order of tens of billions (GLCA, 2009). In the Copenhagen Accord (COP-15, 2009), the sum of USD 30 billions of dollars for the period 2010-12 and USD 100 billions dollar annually by 2020 to address the needs of the developing countries and significant portion is like to channel through Copenhagen Green Climate Fund (UNFCCC 2009b).

7.4.4. Technology Transfer/Cooperation

7.4.4.1. Technology and Climate Change Adaptation

Technologies receive prominent attention both in adaptation to emerging and future impacts of climate change as well as in mitigating current natural disasters. While the importance of transferring technologies from developers/owners to would-be users is widely recognized, the bulk of the literature seems to address the issues at a rather generic level, without going into the details of what adaptation technologies would need to be transferred in different impact sectors from where to where and via what mechanisms. IEA (2001) lists the many kinds of obstacles (institutional, political, technological, economic, information, financial, cultural, legal and participation and consultation) to technology transfer and presents a series of case studies covering a broad range of technologies, economic sectors, geographical regions in mitigation and adaptation in which the transfer of technologies and practices were successful because concerted efforts were made to overcome these obstacles. Agrawala and Fankhauser (2008) review the economic aspects of adaptation. The report does not assess technology transfer but private-public partnership as a policy instrument could well be a mechanism for transferring the required technologies for adaptation projects. In the adaptation literature, publications addressing the transfer of technologies important for reducing vulnerability and increasing the ability to cope with weather-related disasters are even scarcer. This section reviews literature on adaptation technologies and the issues involved in international technology transfer of such technologies.

The Special Report on the Methodological and Technological issues in Technology Transfer by the IPCC defines the term “technology transfer” as a “broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/education institutions” (IPCC 2000, p 3). The report uses a broad and inclusive term “transfer” encompassing diffusion of technologies and technology cooperation across and within countries. It evaluates international as well as domestic technology transfer processes, barriers and policies.

Adaptation to climate change involves more than merely the application of a particular technology (Klein et al. 2005). Adaptation measures include increasing robustness of infrastructural designs and long-term investments, increasing flexibility of vulnerable managed systems, enhancing adaptability natural systems, reversing trends that increase vulnerability, and improving societal awareness and preparedness. In the case of disasters related to extreme weather events, anticipatory adaptation is more effective and less costly than emergency measures; and immediate benefits can be gained from better adaptation to climate variability and extreme events. Some factors that determine adaptive capacity of human systems are the level of economic wealth, access to technology, information, knowledge and skills, and existence of institutions, infrastructure and social capital. For a comprehensive discussion of these issues see Christoplos et al. (2009).

A comprehensive list of “soft” options that are vital to building capacity to cope with climatic hazards with references to publications that either describe the technology in detail or provide examples of its application is available (Klein et al 2000, 2005). For example, the applications in coastal system adaptation various types of geospatial information technologies such as mapping and surveying, videography, airborne laserscanning (lidar), satellite and airborne remote sensing, global positioning systems in addition to tide gauges, historical and geological methods and so forth. These technologies help formulate adaptation strategies (protection vs retreat), implement the selected strategy (design, construction and operation) and provide early warning. Another set of examples includes technologies to protect against sea-level rise: dikes, levees, floodwalls, seawalls, revetments, bulkheads, groynes, detached breakwaters, floodgates, tidal barriers, saltwater intrusion barriers among the hard structural options, periodic beach nourishment, dune restoration and creation, and wetland restoration and creation as examples of soft structural options. A combination of these technologies selected on the basis of local conditions constitutes the protection against extremes events in coastal regions. In addition a series of indigenous options (flood and drought management) that might be valuable in regions to be affected by similar events (Klein et al. 2005, p. 19).

A report by the UNFCCC (2006a) summarizes the technology needs identified by Parties not included in Annex I to the Convention. Curiously, only one country mentioned “potential for adaptation” among the commonly used criteria for prioritizing technology needs. Among 30 technologies listed in the report, it is difficult to find even a single one that would be directly relevant for coping with weather extremes. Another UNFCCC report (2006b) observes that, unlike those for mitigation, the forms of technology for adaptation are often rather familiar. Many have been used over generations in coping with floods, for example, by building houses on stilts or by cultivating floating vegetable plots (see Box 7-1). Some other types of technologies are more recent, involving advanced materials science, perhaps, or remote satellite sensing. The report provides an overview of the old and the new technologies available in adapting to changing environments, including climate change.

_____ START BOX 7-1 HERE _____

Box 7-1. Examples of Adaptation Technologies in Asia

In Asia, Community based adaptation activities to climate change, variability and extreme events are small-scale and concentrate on agriculture, water and natural disaster amelioration (Alam et al. 2007). They typically have an emphasis on livelihood of the impacted community, diversification of agriculture, conservation of water and awareness raising to change practices. For example, Saudi Arabia has already implemented a number of projects to deal with climate related problems. These include construction of 215 dams for water storage, installation of 30 desalination plants, enactment of water protection and conservation regulation, leakage detection and control scheme, an advanced irrigation water conservation scheme and a system for modification of water pumping. Traditional as well as technological approaches are used to cope with the risk of drought in India. Technological management of drought uses medium (seasonal) to long-term (annual to decadal) forecasts that are formulated using appropriate models. This information is then translated into early warning, and subsequently appropriate drought protection measures are taken. Another example is related to the Philippines. After Typhoon Sisang in 1987, which completely destroyed over 200,000 homes, the Department of Social Welfare and Development decided to instigate a programme of providing typhoon-resistant housing for those living in the most typhoon prone areas (Diacon, 1992). The Core Shelter houses are designed to withstand wind speeds of 180 km/h and have typhoon resistant features. The technology proved to be successful and was adopted recently in a region stricken by landslide (Government of the Philippines, 2008) and typhoons Government of the Philippines (2010).

_____ END BOX 7-1 HERE _____

In the process of implementing technologies for adaptation to climate change, one of the critical components is the presence of appropriate and effective institutions (Klein et al. 2000, 2005). Institutions vary widely across scales (small to large, local to national), sectors (such as agriculture, water, forestry, transport) and from formal (*e.g.*, Ministry or Department of Environment, NAPA Secretariat) to informal (*e.g.*, a local village community). Whilst formal institutions can respond to adaptation needs and challenges with regulations, institutional guidelines and allocated resources, informal institutions often respond to specific adaptation challenges such as drought, flood or a cyclone as self-organised and self-motivated systems. In between these two extremes there is a range of institutional arrangements and different degrees of formalisation. For example, NGOs can play important roles in advancing adaptation technologies. Local institutions in adaptation that play a role in adaptation are also important for technology transfer (Agrawal et al. (2008).

7.4.4.2. Financing Technology Transfer

So far most of the attention regarding innovative financing has been devoted to the mitigation side of the climate change challenge. Several financing mechanisms have emerged that aim to catalyze important change agents, facilitate trading of credits (i.e., carbon or renewable energy), and provide greater overall flexibility for the private sector to invest in environmentally sustainable technologies. Nothing comparable has thus far emerged for the adaptation side where potential technology transfer investments are still associated with insufficient incentive regimes, increased risks and high transaction costs.

In the cases of many industrial or energy technologies the results of penetration in the developing countries depended on many factors including skill base at the recipient countries, appropriate market conditions, technology levels and assured supply of services such as electricity and water, appreciation and implementation of quality control, availability of spare parts etc. Often it is a variety of interconnected issues - socio-economic, institutional and governance – that have determined the degree of success of technology transfer, rather than the technologies themselves (Klein, 2005, p. 23).

UNFCCC (2005) contains a summary of the 20 presentations delivered at the seminar on the development and transfer of environmentally sound technologies for adaptation to climate change from 14–16 June 2005, in Tobago, Trinidad and Tobago. The report includes summaries of presentations regarding such issues as needs for, the identification and evaluation of technologies for adaptation to climate change, and financing their transfer. Several participants from developing countries highlighted the need to focus on the means to transfer technology and that cost is one of the highest barriers in technology transfer. Daniele Violetti (UNFCCC Secretariat) presented options for innovative financing for the development and transfer of technology together with a list of potential funding for technology transfer, including bilateral activities of Parties, multilateral activities such as the GEF, the World Bank or regional banks, the Special Climate Change Fund (SCCF), the LDC Fund, financial flows generated by Joint Implementation and clean development mechanism projects, and the private sector. The GEF funds for adaptation activities include four programmes: the Strategic Priority on Adaptation (SPA) trust fund; the LDC Fund; the SCCF; and the Adaptation Fund under the Kyoto Protocol. A sensitive issue in technology transfer is when it involves technologies protected by intellectual property rights and must be implemented in accordance with international law.

Climate variability is already a major impediment to development and 2% of the World Bank funds are devoted to disaster reconstruction and recovery (World Bank, 2008). In order to use available funds efficiently, the World Bank is developing a screening tool to help the user find out what climate vulnerabilities should be addressed in a specific project (UNFCCC, 2005). Both conventional and innovative options for financing the transfer of adaptation technologies might be explored. As conventional options the GEF funds (SPA, LDC Fund, SCCF and Adaptation Fund) provide opportunities for accessing financial resources that could be used for deployment, diffusion and transfer of technologies for adaptation, including initiatives on capacity-building, partnerships and information sharing. Projects identified in technology needs assessments (TNAs) could be implemented using these financial opportunities. Based on these experiences as well as on special needs of groups of countries such as SIDS and LDCs, further guidance could be provided to the GEF on funding technologies for adaptation. In addition, there is an opportunity to explore innovative financing mechanisms that can promote, facilitate and support increased investment in technologies for adaptation (UNFCCC, 2005).

Concerning financing of technological development and transfer, a report by the Expert Group on Technology Transfer (UNFCCC, 2009a) classifies technologies by stage of maturity, the source of financing (public or private sector) and whether they are under or outside the Convention and estimates the financing resources currently available for technology research, development, deployment, diffusion and transfer. The estimates for mitigation technologies are between USD 70 and 165 billion per year. In the adaptation area, the report claims that R&D is focused on tailoring technologies to specific sites and applications and thus the related expenditures become part of the project costs. Current spending on adaptation projects in developing countries is about USD 1 billion per year (UNFCCC 2009a).

7.4.4.3. Technologies for Extreme Events

Approaching the issues of technologies to foster adaptation to extreme weather events and their impacts from the direction of disaster mitigation, Sahu (2009) presents an overview of a broad range of technologies that have wide-ranging potential applications at various stages of disaster management. Technologies for the following applications are covered in the report:

- Early warning and disaster preparedness
- Search and rescue of disaster survivors
- Energy and power supply
- Food supply, storage, and safety
- Water supply, purification, and treatment
- Medicine and healthcare for disaster victims
- Sanitation and waste management in disaster mitigation
- Disaster-resistant housing and construction.

Developing wind-resistant building technologies is crucial in reducing vulnerability to high-wind conditions like storms, hurricanes and tornadoes. A report by the International Hurricane Research Centre (IHRC) presents Hurricane Loss Reduction Devices and Techniques (IHRC, 2006). The Wall of Wind testing apparatus (multi-fan systems that generate up to 130 mph winds and include water-injection and debris-propulsion systems with sufficient wind field sizes to test the construction of small single-story buildings) will permit a fundamental understanding of the failure mode of buildings and hence lead to technologies and products to mitigate hurricane impacts

An absolutely crucial aspect of managing weather extremes both under the present and future climate regime is the ability to forecast and provide early warning. It is important to note that, to the extent it is possible, such systems must provide multi-hazard warning to be really useful. Satellite and aerial monitoring, meteorological models and computer tools including GIS as well as local and regional communication systems are the most essential components. The use of GIS in the support of emergency operations in the case of both weather non-weather disasters becomes increasingly important in the USA. The National Association of State Chief Information Officers (NASCIO, 2006) presents the benefits of using geographic information systems (GIS) technologies to inform the public, enable officials to make smarter decisions, and facilitate first-responders efforts to effectively locate and rescue storm victims. Lack of locally useable climate change information remains an important constraint in managing weather-related disasters. Therefore there is a need to develop regional mechanisms to support in developing and delivering downscaling techniques and tools.

Space technologies (such as Earth observation, satellite imagery, real time application of space sensors, mapping) are important in the reduction of disasters (Rukieh and Koudmani, 2006). The use of such technologies can be particularly useful in the risk assessment, mitigation and preparedness phases of disaster management. Space technologies are also vital to the early warning and management of the effects of disasters. In order for the developing countries to be able to incorporate the routine use of space technology-based solutions there is a need to increase awareness, build national capacity and also develop solutions that are customized and appropriate to the needs of the developing world. Among others issues, Rukieh and Koudmani (2006) also review the importance of space technologies for such extreme weather events as drought, flood, storms, and ice-hazards.

Support for relief agencies and governments depend on timely availability of information (Holdaway, 2001). This support depends on the timely availability of information about the scale and nature of these disasters. Currently ground-based sources provide most of such information. There is an increasing recognition that significant input could be provided by space-based sensor systems, both for disaster warning and disaster monitoring. Recent major disasters have demonstrated that the scale of devastation cannot adequately be monitored from ground-based information sources alone. The author presents recent developments in a study to provide a global space-based monitoring and information system, with the associated ability to provide advanced warning of many types of disaster, together with the latest developments in sensor technology (optical, IR, Radar) including a UK initiative in high resolution imaging from a microsatellite. Microsatellites (unusually low weights and small sizes, just under or well below 500 kg) are seen as an important technology for the detection and preparation for weather related disasters in other countries as well as well. Shimizu (2008) emphasizes the importance of international cooperation in this area. He observes that only a few countries are able to develop large rockets and satellites, and launch them from their own territories. Several Asian countries are currently cooperating with the United States, Europe and other nations to develop small earth observation satellites. Promising satellites include DAICHI (Advanced Land Observing Satellite) and HIMAWARI (Wideband Internetworking engineering test and demonstration satellite) that include both optical and microwave sensors). DAICHI was launched in 2006 and is based on cooperation of Asian countries with the USA and EU (Holdaway 2001).

Based on the session "Disaster Mitigation, Warning Systems and Societal Impact" at the Sixth International Workshop on Tropical Cyclones, Lee et al. (2006) focus on the application aspects of tropical cyclone forecasting and warnings, and the way such information is conveyed to stakeholders, users and the general public for the mitigation of adverse cyclone impacts. An effective warning system incorporates two components: reliable forecasting of tropical cyclones and efficient conveyance of warning information. Among others such measures as satellites, EPS (Ensemble Prediction System) are increasingly becoming important. NMHSs (National Meteorological and Hydrological Services) should take advantage of the advances in communication technology such as wireless broadband access, GPS and GIS to enhance the relevance and effectiveness of warnings, options and backup capabilities to disseminate warnings through multiple and diverse channels with a variety of high and low technology.

Groat (2004) address a major challenge in natural hazards research that is turning real-time data from new technologies (e.g. satellite and ground-based sensors and instruments) into information products that people can use to make better decisions about their safety and prosperity. The issue of tracking floods is taken as an example. The most common method for measuring open-channel flow has remained unchanged for more than 100 years. A technician is suspended over a river in a cable car or stands on a bridge while lowering a propeller- type current meter into the fast-flowing water to calibrate the changing relationship between river stage and discharge. The method can be hazardous, especially during floods when information on flow velocity is most needed. Recently, two advances have contributed to improved speed and accuracy of making direct stream flow measurements. First, acoustic Doppler current profilers (ADCPs), attached to a moving boat, send acoustic energy into the river and reflect from particulate matter suspended in the water. The second advance in protecting lives from flood hazards results from the capability to predict the timing, locations, and severity of forecasted floods. By combining detailed digital elevation models (produced by high-resolution LIDAR mapping from low-flying airplanes) with a robust, efficient, two-dimensional flow model, the extent of a predicted flood can be mapped a few days to a week before the flood begins.

The literature about technology transfer to foster adaptation to changes in extreme events induced by climate change is very limited. However, by broadening the scope to climate change adaptation in general, lessons about the processes, channels, stakeholders and barriers can be gained. In addition, useful insights might be inferred from the literature on technology transfer to support climate change mitigation, natural disaster preparedness and management, and other related areas.

7.4.5. Risk Transfer, Risk Sharing

7.4.5.1. Introduction

This section examines the current and potential role of the international community – international financial institutions (IFIs), NGOs, development organizations, private market actors, and the emerging adaptation community – in enabling access to insurance and other financial instruments that share and transfer risks of extreme weather. The international transfer and sharing of risk is an opportunity for individuals and governments of all countries that cannot sufficiently diversify their portfolio of weather risk internally, and especially for individuals Governments of vulnerable countries that do not wish to rely on ad hoc and often insufficient post-disaster assistance. The international community can play a role in enabling individual, national and international risk transfer strategies, and this discussion identifies successful practices, or value added, as well as constraints on this role.

7.4.5.2. International Risk Sharing and Transfer

The Bali Action Plan calls for 'consideration of risk sharing and transfer mechanisms, such as insurance' as a means to address loss in developing countries that are particularly vulnerable to climate change (Decision 1/CP.13, Bali Action Plan). Similarly the Hyogo Protocol calls on the disaster community "to promote the development of financial risk-sharing mechanisms, particularly insurance and reinsurance against disasters" (ISDR, 2005a: 11).

Risk transfer and risk sharing are pre-disaster financing arrangements that shift economic risk from one party to another. These arrangements, which include informal instruments (e.g. remittances) and formal market instruments (e.g., insurance), can be an essential part of an overall adaptation strategy. They do not reduce overall risk or losses, and in the case of insurance they increase the expected average loss; yet, by smoothing consumption, financial instruments protect against catastrophic losses and by supplying timely capital for recovery, they reduce long-term indirect disaster impacts. They also provide the security necessary for productive investments, thus promoting development and helping the most vulnerable escape disaster-related poverty traps (Barnett et al., 2008). At the same time, poorly designed instruments can lead to disincentives for reducing disaster risks (moral hazard), and public and international interventions can crowd out private sector operations and investments. These drawbacks should be viewed in relation to the alternative of international post-disaster aid, which, in theory, reduces incentives for and expenditures on ex-ante prevention (Raschky and Weck-Hannemann, 2007; Linnerooth-Bayer, et al., 2005).

Often by necessity risk transfer is international. Local and national pools (discussed in Chapters 5 and 6) may not be viable for statistically dependent (co-variant) risks that cannot be sufficiently diversified. A single event can cause simultaneous losses to many insured assets, violating the underlying insurance principle of diversification. For this reason, primary insurers, individuals and governments (particularly in small countries) rely on risk sharing and transfer instruments that diversify their risks regionally and even globally.

A few examples can serve to illustrate international arrangements for sharing and transferring risk:

- A government receives international emergency assistance and loans after a major disaster
- A family locates a relative in a distant country, who provides post-disaster relief through remittances
- After a major disaster, a farm household takes out a loan from an internationally backed micro-lending institution
- An insurer purchases reinsurance from a private reinsurance company, which spreads these risks to its international shareholders
- A government issues a catastrophe bond, which transfers risks directly to the international capital markets
- Many small countries form a catastrophe insurance pool, which diversifies their risks and better enables them to purchase reinsurance.

Not only are these financial arrangements international in character, but they are increasingly supported by the international development and climate adaptation communities (see, especially, ISDR (2005) and UNFCCC (2009b). At the outset it is important to point out that these instruments cannot stand alone but must be viewed as part of a risk management strategy, for which cost-effective risk reduction is priority. This section briefly describes the range of financial instruments available for sharing and transferring the risks of extreme climate-related events, and concludes with a discussion of the value added by international organizations.

7.4.5.3. Informal Risk Sharing through Remittances

Reciprocal arrangements, including inter-household transfers, spread risks spatially and might be considered a precursor of formal market pooling or insurance arrangements. Quantifying the prevalence of inter-household transfers is, owing to its informal and multi-definitional nature, inherently difficult. Yet combined analysis of multiple surveys indicates that about 40 per cent of developing country households are involved in private transfers in a given year, either as recipients or donors, or both (Cox and Fafchamps, 2007). Local informal risk sharing is inherently restricted by limited resources and diversification opportunities.

Remittances, transfers of money from foreign workers or ex-pat communities to their home countries, make up a large part of these informal transfers, even exceeding official development assistance. In 2006, the official worldwide flow of remittances is estimated at $268 million, and unrecorded flows through informal channels may add another 50% or more. In some cases, remittances can be as large as a third of the recipient country's GDP (World Bank, 2006).

A number of studies show that remittances increase substantially following disasters, often exceeding post-disaster donor assistance (Lucas and Stark, 1985; Miller and Paulson, 2007; Yang and Choi, 2007; Sanket et al., 2009). Payments can be sent through formal, standard means such as banks or professional money transfer organizations, but often these channels break down and remittances are carried by hand (Savage and Harvey (2007). While remittances are simple in concept, their use can be complicated by associated transfer fees. A survey carried out in the UK found that for an average-sized transfer, the associated costs could vary widely between 2.5% and 40% (DFID, 2005). Information pertinent to the transfer is often obscure or in a language unfamiliar to the worker sending funds, and as such, they do not have access to all possible options. Remittance transfers have been complicated across some borders due to initiatives taken by developed nations to counter international money laundering and financing of terrorism (Fagen and Bump, 2007). Finally, a major problem facing post-disaster victims is difficulties in communicating with relatives abroad, and the subsequent inability to request aid, as well as the high potential to lose necessary documents in a disaster.

The international community has been active in reducing the costs and barriers to post-disaster remittances. DFID, among other development organizations, supports financial inclusion policies including mobile banking and special savings accounts earmarked for disaster recovery that will greatly reduce transaction costs. High-tech proposals for assuring security have included biometric identification cards and retina scanners as forms of identification.

7.4.5.4. Post-Disaster Credit

As one of the most important post-disaster financing mechanisms, credit provides governments, individuals and households with resources after a disaster, but with an obligation to repay these resources at a later time. Governments and individuals of highly vulnerable countries, however, can have difficulties borrowing from commercial lenders in the post-disaster context. Since the early 1980s, the World Bank has thus initiated over 500 loans for emergency recovery and reconstruction purposes for a total disbursement of more than USD 40 billion (World Bank, 2006), and the Asian Development Bank also reports large loans for this purpose (Arriens and Benson, 1999).As a recent innovation, international organizations are making pre-disaster contingent loan arrangements, for example, the World Bank's catastrophe deferred drawdown option (CAT DDO), which disburses quickly after the borrowing government declares an emergency (World Bank, 2008).

For micro-finance institutions (MFIs), post-disaster lending has associated risks since increased demand can challenge the liquidity of credit organizations and tempt relaxed loan conditions or even debt pardoning. This risk is particularly acute in vulnerable regions. A risk transfer instrument can help MFIs remain solvent in the post-disaster period. Recognizing this, the Swiss State Secretariat for Economic Affairs (SECO) and the Inter-American Development Bank (IADB), as well as private investors, created the Emergency Liquidity Facility (ELF). Located in Costa Rico, ELF provides needed and immediate post-disaster liquidity at break-even rates to MFIs across the region. Low-interest credit enables MFIs to continue extending affordable credit in time of crisis. Of equal importance, ELF provides fledgling MFIs with technical know-how to make their operations disaster proof.

7.4.5.5. Insurance and Reinsurance

As an instrument for distributing disaster losses among a pool of at-risk households, businesses and/or governments, insurance is the most recognized form of international risk transfer. The insured share of property losses from extreme weather events has risen from a negligible level in the 1950s to approximately 20 per cent of the total in 2007 (Mills, 2007). With primary and reinsurance markets attracting capital from international investors, insurance has become an instrument for transferring disaster risks over the globe. This market is highly international in character. For example, in the period 2000-2005 U.S. insurers purchased reinsurance annually from more than 2,000 different non-U.S re-insurers (Cummins and Mahul, 2009: 115)

World-wide insurance for climate-related losses is unevenly distributed. From 1980 through 2003 insurance covered 4 per cent of total losses from climate-related disasters (estimated at about USD 1 trillion) in developing countries compared to 40 per cent in high-income countries (Munich Re, 2003).

The international community has played a formidable and essential role in many recent micro- and sovereign (macro) insurance initiatives as a few examples (discussed in Chapters 5 and 6) illustrate:

- The World Bank and World Food Programme provided essential technical assistance and support for establishing the Malawi pilot micro-isurance program, which provides index-based drought insurance to smallholder farmers (Suarez, et al., 2007; Hess and Syroka, 2005)
- The Mongolian government and World Bank support the Mongolian Index-Based Livestock Insurance Program by absorbing the losses from very infrequent extreme events (over 30 per cent animal mortality) and providing a contingent debt arrangement to back this commitment, respectively (Skees, et al., 2008; Skees and Enkh-Amgalan, 2002)
- The World Food Programme (WFP) successfully obtained an insurance contract through a Paris-based reinsurer to provide insurance to the Ethiopian government, which assures capital for relief efforts in the case of extreme drought (Hess, 2007)
- The governments of Bermuda, Canada, France, the United Kingdom, as well as the Caribbean Development Bank and the World Bank have recently pledged substantial contributions to provide start-up capital for the Caribbean Catastrophe Risk Insurance Facility (discussed below) (Cummins and Mahul, 2009).

These early initiatives, especially micro-insurance schemes, are showing promise in reaching the most vulnerable, but also demonstrate considerable challenges to scaling up current operations. Lack of data, regulation, trust and knowledge about insurance are some of the barriers (Hellmuth, 2009; Miamidian, 2005).

Insurance and other risk financing instruments are particularly effective when used in conjunction with risk-reduction activities. Supporters point out that insurance contracts with premiums based on risk will reward preventive behaviour, and Kunreuther and Michel-Kerjan (2009) show how this incentive could be more effective if insurers offered long-term contracts. Insurance can also be directly linked to risk reduction. As one innovation, a micro-insurance scheme in Ethiopia is providing reduced premiums to farmers who provide their labour in the off season for risk-reducing projects (Suarez et al., 2009).

7.4.5.6. Alternative Insurance Instruments

Alternative insurance-like instruments, sometimes referred to as risk-linked securities, are innovative financing devices that enable risk to be sold in international capital markets. Given the enormity of these markets, there is large potential for alternative or non-traditional risk financing, including catastrophic risk (CAT) bonds, industry loss warranties (ILWs), sidecars, and catastrophic equity puts, all of which are playing an increasingly important role in providing risk finance for large loss events. A discussion of these instruments goes beyond the scope of this chapter, but we draw attention to the most prominent risk-linked security, the CAT bond, which is a fully collateralized instrument whereby the investor receives an above-market return when a specific catastrophe does not occur (e.g. a hurricane category 4 or greater), but shares the insurer's or government's losses by sacrificing interest or principal following the event. Insurers and reinsurers in developed countries account for over 95% of cat bonds by issue volume. Although it is still an experimental market, the annual stream of CAT bond issues more than doubled between 2005 and 2006, with a peak at $4.7 billion in 2006 (Cummins and Mahul, 2009).

In 2006 and 2009 the first government-issued disaster-relief CAT bond placements were executed by Swiss Re and Deutsche Bank Securities to provide funds to the government of Mexico to defray costs of disaster recovery and relief. The World Bank provided technical assistance for these transactions. The first bond transferred $160 million of Mexican earthquake risk to the international capital markets through a special-purpose vehicle. Although the transaction costs of this placement were large, and basis risk and counterparty credit risk are impediments to the success of these contracts, it is expected that this form of risk transfer will become increasingly attractive especially to highly exposed developing country governments (Lane, 2004). As discussed in Chapter 6, a large number of governments are vulnerable to catastrophic risks, and post-disaster financing strategies generally have high opportunity costs for developing countries

Donor organizations have played an important role in another case of sovereign risk transfer. In 2006 the World Food Programme (WFP) purchased an index-based insurance instrument to support the Ethiopian government-sponsored Productive Safety Net Programme, which provides immediate cash payments in the case of food emergencies (Wiseman and Hess, 2007). While this transaction relied on traditional re-insurance instruments, there is current interest in issuing a CAT bond for this same purpose. Tomasini and Van Wassenhove (2009) note inter alia the important role that securitized instruments/insurance can play in assuring the financial wherewithal for humanitarian aid when disasters strike.

7.4.5.7. International Risk Pools

Catastrophe insurance pools are a promising innovation that enables highly vulnerable countries, and especially small states, to more affordably transfer their risks. By pooling risks across individual countries, regions and the world, catastrophe insurance pools generate diversification benefits that are reflected in reduced insurance premiums. In addition, by accumulating reserves over time, pools are able to increase risk retention, thereby allowing further reduction in insurance premiums. Finally, there is growing empirical evidence that catastrophe insurance pools have been able to diversify inter-temporally to dampen the volatility of the reinsurance pricing cycle and offer stable premiums to the insured countries. (Cummins and Mahul, 2009)

As a recent example, the Caribbean Catastrophe Risk Insurance Facility (CCRIF) was established in 2007 to provide Caribbean Community (CARICOM) governments with an insurance instrument at a significantly lower cost (about 50% reduction) than if they were to purchase insurance separately in the financial markets. Governments of 16 island states contributed resources depending on the exposure of their specific country to earthquakes and hurricanes, and claims will be paid depending on an index for hurricanes (wind speed) and earthquakes (ground shaking). Early cash payments received after an event will help to overcome the typical post-disaster liquidity crunch (Ghesquiere et al., 2006; World Bank, 2007a, 2007b). The governments of Bermuda, Canada, France, the United Kingdom, as well as the Caribbean Development Bank and the World Bank recently pledged a total of US $47 million to the CCRIF reserve fund.

7.4.5.8. Value Added by International Interventions

International Financing Institutions (IFIs), donors and other international actors have played a strongly catalytic role in the development of catastrophic risk financing solutions in vulnerable countries, most notably by:

- *Exercising convening power*, for example, the World Bank coordinated the development of the CCRIF
- *Supporting public goods* for development of risk market infrastructure, for example, donors could fund weather stations necessary for index-based weather derivatives
- *Providing technical assistance*, for example, the World Food Programme carried out risk assessments and provided other assistance for the Ethiopian sovereign risk transfer, and the World Bank provided technical assistance for the Mexican CAT bond
- *Enabling markets*, for example, DFID is active in creating the legal and regulatory environment to facilitate access to banking services, which, in turn, greatly expedite remittances
- *Financing risk transfer*, as examples, the Bill Gates Foundation subsidizes micro-insurance in Ethiopia; the World Bank provides low-cost capital backing for the Mongolian micro-insurance program; Swiss SECO and IDB provide low-interest credit to the ELF, and many countries have contributed to the CCRIF fund.

These are only a few examples of increasing involvement by the international community in risk sharing and transfer projects. They show that international financial institutions and development/donor organizations can assist and enable risk sharing and transfer initiatives in diverse ways, which raises the question of their value added. Largely uncontested is the value of creating the institutional conditions necessary for community-based risk sharing and market-based risk transfer; yet, direct financing, especially of insurance, is controversial. Supporters point to the "solidarity principle" discussed in Section 7.2.2 and the important role that solidarity has played in the social systems of the developed world (Linnerooth-Bayer and Mechler, 2008). Critics point to the "efficiency principle" (discussed in Section 7.2.4) and argue that public and international support, especially in the form of premium subsidies, can distort the price signal and weaken incentives for taking preventive measures, thus perpetuating vulnerability. Other types of support, like providing reinsurance to small insurers, can crowd out the (emerging) role of the private market. Finally, critics point out that it may be more efficient to provide the poor with cash grants than to subsidize insurance.

Recognizing these concerns, most commentators agree that there are important and valid reasons for interfering in catastrophe insurance and other risk-financing markets in specified contexts (Cummins and Mahul, 2009; Linnerooth-Bayer et al., 2010), especially if:

- The private market is non-existent or embryonic, in which case enabling support (e.g., to improved governance, regulatory institutions, as well as knowledge creation) may be helpful.
- The private market does not function properly, in particular, if premiums greatly exceed the actuarially fair market price due, eg., to limitations on private capital and the uncertainty and ambiguity about the frequency and severity of future losses (Kunreuther, 1998). In this case economically justified premiums that are lower than those charged by the imperfect private market may be appropriate (Cutler and Zeckhauser, 1999; Froot, 1999).
- The target population cannot afford sufficient insurance cover, in which case financial support that does not appreciably distort incentives may be called for. The designers of the Mongolian program, for example, argue that subsidizing the "upper layer" is less price-distorting than subsidizing lower layers of risk because the market may fail to provide insurance for this layer (Skees, et. al., 2008).
- The alternative is providing "free" aid after the disaster happens.

7.4.5.9. Proposals for Insurance as Part of an Adaptation Strategy

Recognizing that insurance is not appropriate in all contexts, and that it must be viewed as only a part of a comprehensive risk-management program, two proposals for including insurance in an adaptation regime have recently been put forward. The Munich Climate Insurance Initiative (MCII) proposes a two-pillar Risk Management Module as part of an adaptation regime (MCII, 2008), and almost identically, the Alliance of Small Island States (AOSIS) proposes a three-component Multi-Window Mechanism (AOSIS, 2008). Both include provisions for supporting preventive measures and for enabling micro- and national insurance systems (as well as regional pools) in vulnerable developing countries by providing technical assistance, capacity building and possibly absorbing a portion of the insurance costs. Both proposals also have important elements not shared by the other. MCII suggests a Climate Insurance Pool that indemnifies victims of extreme catastrophes in vulnerable countries by a percentage of their losses, where premiums are paid fully by an adaptation funding mechanism. AOSIS suggests a rehabilitation/compensatory component that would compensate victims for sea-level rise and other uninsurable damages.

7.4.6. Knowledge Creation, Management, and Dissemination

The growing concern on increasing incidents of disasters globally has put great pressure on the need for knowledge generation, management and dissemination in the field of disaster risk management. The various DRR measures noted above, e.g. risk transfer, technology development and transfer, legal aspect and so forth will be of use where they are known and fully understood to the extent that they can be assimilated in DRR at all scales. An internationally agreed mechanism for generation, storage and retrieval and sharing of integrated climate change risk information, knowledge and experiences is yet to be established (Sobel and Leeson, 2007). Where knowledge generation, sharing and dissemination is achieved it is fragmented, assumes a top-down approach, sometimes this is carried out by institutions with no clear international mandate and the quality of the data and its coverage are inadequate. In other cases huge amount of information is collected but not efficiently used (Zhang et al., 2002; Sobel and Leeson, 2007). Access to data or information under Government institutions is often constrained by bureaucracy and consolidating shared information can be hampered by multiple formats and incompatible datasets. The major challenge in achieving coordinated integrated risk management across scales is in establishing clear mechanisms for a networked programme to generate and exchange diverse experiences, tools and information that can enable various actors at different levels to different options available for reducing climate risks. Such a mechanism will support efforts to mainstream disaster management into development for example, in the case of initiatives by UNDP; development organisations such as the World Bank, DFID and Inter-American Development Bank (IDB); bilateral organisation such as Canadian International Development Agency (CIDA), European Commission (EC) and so forth (Benson et al., 2007).

Attempts have been made to improve information sharing and dissemination for disaster relief. UNOCHA established the ReliefWeb (http://www.reliefweb.int) in 1996 to act as a clearinghouse for humanitarian information and has since 2002 organised four gatherings on humanitarian information management and exchange for various disasters (Wolz and Park, 2006; Maitland and Tapia 2007; Saab et al., 2008).

7.4.6.1. Knowledge Organization, Sharing, and Dissemination

International climate change risk management requires integration of different types of information, knowledge and experiences and their effective dissemination for use in determining levels of exposure and vulnerabilities across temporal and geographical scales to establish appropriate action (Louhisuo et al., 2007; Kaklauskas et al., 2009). The need for a global strategy to effectively amalgamate and share existing knowledge across scales was noted by Marincioni, 2007. For example, accounting for climate risks within the development context will among others be effectively achieved where appropriate information and knowledge of what is required exit and is known and shared. In disaster relief, comprehensive and authoritative information facilitate appropriate response and recovery measures to be implemented (Zhang et al., 2002). Collaboration among scientists of different disciplines, practitioners, policymakers and the public is pertinent in knowledge creation, management and accessibility (Thomalla et al., 2006). The type, level of detail and ways of generation and dissemination of knowledge will vary across scale i.e. from the local level where participatory approaches are used to incorporate indigenous or local knowledge and build collective ownership of knowledge generated; to the broader regional to international levels thus providing for the application of the principle of subsidiarity in the organisation, sharing and dissemination of disaster risk management (Chagutah, 2009).

In recognition of geographical differences and various levels of needs for humanitarian information, UNOCHA held a Global Symposium on humanitarian information management in Geneva 2002 which was followed by three similar regional humanitarian information network workshops in Bangkok, Panama, and Nairobi between 2003 and 2006 (Maitland and Tapia 2007; Saab et al., 2008). Exchange of disaster information worldwide has increased tremendously through for example, mass media and Information and Communication Technologies (ICT). In a disaster situation survival and recovery are closely linked to provision of effective communication prior to and throughout the disaster situation (Paul, 2001). Mass media e.g. Radio, Television sets and newspapers are powerful mechanisms for conveying information during and immediately after disasters although they may over sensationalize issues (Vasterman et al., 2005). Further the media do not operate in a social vacuum and as a result a “two-step flow” approach where the mass media is combined with interpersonal communication channels have been found to provide a more effective approach to information dissemination (Chagutah, 2009; Kaklauskas et al., 2009).

Increased use of information communication technology (ICT) such as mobile phones, online blogging and real time crowd-souring electronic commentary and other forms of social networked communications such as Twitter, Facebook etc. all represent current tools for timely delivery of disaster information to people who need it, that is if the information is given in an appropriate format, and language. There are emerging attempts to develop mobile phone based disaster response services such as systems that can translate disaster information into different languages (Hasegawa et al., 2005); and use real-time mobile phone calling data to provide information on location and movement of victims in a disaster area (Madey et al., 2007)**.** The UN OCHA ReliefWeb site for humanitarian so far offer the largest internet based international disaster information gathering, sharing and dissemination although there are other initiatives such as the NetHope International which combines development and disaster issues into its IT-centric mandate (Saab et al. 2008) and services that augments the RelifWeb such as the International Charter which provides space data (http://www.disasterscharter.org).

While the use of mobile phones and Internet facilities have fast penetrated different parts of the world including developing countries their potential in disaster relief is not yet fully exploited. For disaster relief, the UN OCHA ReleifWeb poorly represents local to national level humanitarian activities (Wolz and Park, 2006) and does not cover preparedness and disaster prevention. There are still large sections of the global population who have no access to Internet and other telecommunication service (Samarajiva, 2005) although evidence shows that improved access by disaster workers has overall positive effects on disaster relief (Paul, 2001; Wolz and Park, 2006). Sustainable use of ICT for coordination of information for humanitarian efforts face challenges of limited resources to mount, maintain and upgrade these systems because donors demand that overhead expenses, including IT, should be kept to a minimum (Saab et al., 2008). ICT is also limited to explicit knowledge that is comprised of, e.g., documents and data stored in computers but lacks tacit knowledge that is based on experience linked to someone's expertise, competence, understanding, professional intuition and so forth that can be valuable for disaster relief (Kaklauskas et al., 2009). Increased international collaboration on disaster management provides for the filtering of tacit knowledge, therefore 'best practices' across regions.

Nevertheless as with humanitarian needs, the use of information technologies (IT) e.g. computer networks, digital libraries, satellite communications, remote sensing, grid technology, Geographic Information Systems (GIS), for disaster risk reduction has also significantly increased data and information exchange on risks (UN ISDR, 2005b; Louhisuo et al., 2007). IT offers interactive modes of learning which could be of value in distance education and online data sharing and retrieval e.g. the Center for Research on the Epidemiology of Disaster (CRED) Belgium (http://www.cred.be/) maintains the Emergency Events Database (EM-DAT) which has over 18,000 mass of disasters in the world from 1900 to present. This data is useful for disaster preparedness, and vulnerability assessments (CRED, 2006). In addition enhancing interaction among individuals and institutions from national, regional to international level e.g. through e-mail, newsgroups, on-line chats, mailing lists and web forums is an important contribution of IT capabilities in disaster risk reduction (Marincioni, 2007). Attempts have been made for example ,in Japan to create an integrated disaster risk reduction systems where mobile phone communication operates as part of a greater information generating and delivery chain that includes earth observation data analysis, navigation and web technologies, GIS and grid (Louhisuo et al., 2007).

The emergence of a facility such as the PreventionWeb (www.preventionweb.net/) under the UN ISDR in support of the HFA, signal the huge potential of IT in information sharing for international disaster risk management across scales. PreventionWeb has been evolving since 2006 with the purpose of becoming a single entry point to the full range of global disaster risk reduction activities and hence provides a common platform for institutions to connect, exchange experiences and share information on DRR. This is similar to the case of reliefweb described above for humanitarian needs. Updated daily, the PreventionWeb platform contain news, DRR initiatives, event calendars, online discussions, contact directories, policy and reference documents, training events, terminology, country profiles, factsheets as well as audio and video content and hence while it caters primarily for professionals in disaster risk reduction it also promotes better understanding of disaster risk by non-specialists. PreventionWeb is a response to a need for greater information and knowledge sharing and dissemination advanced in Zhang et al. (2002), Marincioni, (2007), Kaklauskas et al. (2009) and others.

However, in all the information tools noted, the quality of information transferred and language used influence their effectiveness and often these mechanisms collapse during a disaster when most needed (Marincioni, 2007; Saab et al., 2008). Some of the new technologies are not easily accessible to the very poor. There are differences in perception on the role of IT in exchange of disaster knowledge as opposed to its role in increased flow of information, with knowledge here defined simple as understanding of information while information refers to organized data (Zhang et al., 2002; Marincioni, 2007). Others conclude that while there is increased circulation of disaster information this does always result in increased assimilation of new risk reduction approaches, a factor which is partly attributed to lack of effective sharing (Zhang et al., 2002; ISDR, 2005b).The level of assimilation of

IT technology in disaster risk reduction depends among others on levels of literacy and working environment including institutional arrangements hence effectiveness may vary with levels of development (Marincioni, 2007;Samarajiva, 2005). As a result the contribution of facilities such as PreventionWeb will among others depend on accessibility and assimilation of IT in daily operations of institutions across the globe. Others note further that information alone is not adequate to address disaster risk reduction rather other factors such as availability of resources, effective management structures and social networks are critical (Chagutah, 2009).

In addition, one major constrain in climate change risk management is that for sometime communities working in disaster management, climate change and development have operated separately even though they are all concerned with human wellbeing. For e.g. emphasis on humanitarian assistance has been attributed to faulty development leading to increased vulnerability (Benson and Twigg, 2007), while development community members are for example likely to be better equipped on use of insurance but fail to link this to climate risk reduction. Similar observations have been made on cities where urban developers have no link with climate risk management community (Wamsler, 2006). Linkages among these communities through coordinated knowledge sharing are an important part of global security (Schipper and Pelling, 2006).

Communication gaps between professional groups often results from different language styles and jargons. Heltberg, (2008) has suggested a need for establishing universally shared basic operational definition of key terms such as risk, vulnerability, and adaptation across the different actors as a basis for dissemination of knowledge a factor also noted by others e.g. for better coordination among numerous humanitarian organization (Saab etal., 2008) and the FAO guide for disaster risk management (Baas et al., 2008). The move towards establishment of National Disaster Risk Reduction institutions that link to similar regional and international structures by for example UN ISDR provides a framework for bringing different stakeholders together including climate change and development community at the national level culminating in greater integration of risk management at the international level. Other efforts include international initiatives to integrate, at the national level, disaster risk reduction with poverty reduction frameworks (Schipper and Pelling, 2006).

7.4.6.2. Knowledge Generation

Integrated risk management requires skilful use of different types of knowledge (scientific, social sciences, traditional knowledge, etc) (Heltberg, 2008). Such knowledge needs to be generated, documented and evaluated for its authenticity and applicability over time and beyond its point of origin (Rautela, 2005). Knowledge generation has to focus on the initiated shift in emphasis by HFA from reactive emergency relief to pro-active disaster risk reduction to strengthen prevention, mitigation and preparedness. The Global Spatial Data Infrastructure (GSDI) which aims to coordinate and support the development of Spatial Data Infrastructures world-wide provides important services for a pro-active disaster risk reduction approach (Köhler and Wächter, 2006). There are huge efforts in knowledge generation and exchange by universities, government agencies, international organizations and the private sector but coordination of these efforts internationally is yet to be achieved (Marincioni, 2007).

The generation of climate change information has followed a top down approach by using global models to produce broad scale information usually with large uncertainties and complex for the public to assimilate hence providing no incentive for policy makers to act on the risks that are indicated (Weingart et al., 2000;Schipper and Pelling, 2006). Climate change information by its definition has to be provided at long temporal ranges, e.g. 2050, which is far beyond the 5 year attention span of political governments let alone that of the poor people concerned with basic needs. The ongoing effort to enhance delivery of information at inter-annual to inter-decadal scale will improve assimilation of climate information in risk management. Further, expressing impacts, vulnerability and adaption require description of complex interactions between biophysical characteristics of a risk and socioeconomic factors and relating to factors that usually span far beyond the area experiencing the risk. Communicating these linkages has been a challenge particularly in developing countries where education levels are low and communication networks are poor. In general locally relevant climate change risk information is lacking and the capacity to generate such information is inadequate a factor contributing to vulnerability.

Knowledge generation requires capacity in terms of skilled manpower, infrastructure and appropriate institutions and funding. Long-term research and monitoring with a wide global coverage of different hazards and vulnerabilities is required (Kinzig, 2001). For e.g. forecasting a hazards is a key aspect of disaster prevention but generating such information comes with a cost. Although weather forecasting through meteorological networks of WMO is fast improving, the network of meteorological stations is far from being adequate spatially and some are not adequately equipped. Forecasters are challenged to communicate forecasts that are often characterized by large uncertainty but which need to be conveyed in a manner that can be readily understood by policy and the public (Carvalho, 2007).

Interdisciplinary knowledge generation i.e. bridging the traditional divide among the social, natural, behavioural, and engineering sciences continues to be a great intellectual challenge in risk reduction. For e.g. despite the value of IT in information retrieved through the Internet, such information is rarely cross disciplines to provide building of balanced knowledge on risk management (Marincioni, 2007).

In conclusion literature shows that data and information on their own are not a complete solution to risk reduction. Resources to supply information in a usable form for each unique case so as to translate this to knowledge and action are a critical dimension in risk reduction. Sharing experiences is also important. The international community needs to identify what information is essential for different stages of climate change risk management, how it should be captured and used by different actors under different risk reduction scenarios. Great effort has been put on data, information and knowledge generation and management for disaster relief but this is now changing to incorporate risk management although this is at a rudimentary stage.

7.5. Consideration for Future Policy and Research

7.5.1. Parallel Paths: Disaster Risk Reduction and Climate Change Adaptation

Disaster risk reduction/management and climate change adaptation have common objectives (building resilience) and potential for shared benefits (decreasing future risk and vulnerability) despite having long existed on different policy and research platforms and agendas (Davies, et al., 2008). The adoption of the 1990s as the International Decade for Natural Disaster Reduction can be considered as the first concrete step made by the international community towards the creation of substantial programmes to mobilise efforts at the international level for reducing disaster risks and vulnerabilities. While the release of the IPCCs Third Assessment Report in 2001, containing the chapter, “Adaptation to Climate Change in the Context of Sustainable Development and Equity”, similarly, can be marked as one of the dominant steps pushing adaptation forward in the spotlight with the Marrakesh Accord during COP-7 in 2002 further lifting adaptation issues in the development agenda and strengthening the adaptation profile. Since then, CCA and DRR have separately been gaining ground within the development discourse. Historically, climate change was viewed as an environmental pollution issue with international agreements narrowly focused on mitigation, while neglecting other responses including adaptation (Burton et al. 2007). This misconception of CCA also separated it from its similarities to DRR. Disasters and risk reduction is now included in the Bali Action Plan (BAP) text - Decision 1/CP.13 (from BAP) states that, “Enhanced action on adaptation, including inter alia, consideration of: risk management and risk reduction strategies, including risk sharing and transfer mechanisms such as insurance; (iii) Disaster reduction strategies and means to address loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to the adverse effects of climate change.” Both DRR and CCA are now being viewed in the context of sustainable development with one of the strategic goals of the HFA being the strengthening of the “integration of disaster risk considerations into sustainable development policies, planning and programming at all levels, with a special emphasis on disaster prevention, mitigation, preparedness, and vulnerability reduction”. Similarly, the UNFCCC includes the need of “...implementation of adaptation actions on the basis of sustainable development policies”.

While the knowledge on DRM has advanced considerably, the progress remains behind the level that is required to deal with the increasing challenge of disaster and climate risks and extremes. Some promising efforts have been made through NAPAs in LDCs and Nairobi Work Programme, as well as actions by multilateral and bilateral agencies (Ref ??). However, advancement of CCA awaits further acceleration under a proactive international regime supported by consensus and agreement among developed and developing countries..There has also been some successful piloting on adaptation at the local regional and in some cases at the national level (see Chapter 6) but these are yet to form a critical mass for up-scaling at the international level. While there is available knowledge on adaptation to climate extremes in some quarters its application is still very limited. As highlighted in the Global Assessment Report by UN ISDR, the adaptation agenda lacks organisational leadership at all level. This problem is rooted in the lack of consensus and concrete guidance from the international communities, confusion and differing views among professionals and decision makers first on what adaptation is as opposed to development is and on what it means to integrate DRR-CCA into development.

7.5.2. Synergies and Integration of DRR and CCA

Recently, synergies are being increasingly identified between DRR and CCA (O'Brien, et al., 2006; Thomalla et al., 2006). This trend is likely to continue, resulting in DRR and CCA to be more commonly found on the same research and policy platforms. While hazards classified under DRR and CCA differ, the overlap between climatic hazards is strong – both consider other hazards and impacts (DRR including seismic activity and CCA including biodiversity and desertification). ISDR stated that governments have recognized the importance of coordinating their climate change adaptation plans with disaster risk reduction measures. They also recognize that these policies should be incorporated into their development and poverty eradication programmes (UN ISDR, 2008). With that, ISDR secretariat stated they support these efforts in three areas: Achieving recognition, understanding and the development of specific policies at the international level on the synergies between reducing disaster risk and responding to climate change; Mobilizing, guiding and facilitating action at national and regional levels to integrate disaster reduction and climate change policies and practice; and Strengthening the capacities of the ISDR system to support the integration of disaster reduction and climate change by all actors (UN ISDR, 2008). The capacity for DRR and CCA are highly dependent upon an acceleration of international efforts to reduce greenhouse gas emission. If such an effort is absent or delayed then the tasks of DRR and CAA will become significantly greater and there is a danger in some sectors of exceeding the limits of adaptation (Adger, 2009). Nevertheless much can be achieved by adaptation, although this has yet to be tested and the past record of adaptation to extreme climate-related events is not so encouraging. Losses have continued to rise (Haque and Burton, 2005). The evidence suggests that DRR and CCA could be made more effective by strengthening the capacities and local governments to integrated DRR and CAA into a broader management strategy to ensure availability of safe low risk land for development, more secure land tenure, infrastructure and services and adequate disaster resistant housing especially for the urban poor. Additional investment in natural resource management, ecosystem services, infrastructure development and livelihood generation and strengthening could help to reduce vulnerability and strengthen the resilience of rural areas. A stronger shift from post-disaster relief and reconstruction towards pre-event adaptation could lower the impacts of climate extremes (Helmer, and Hilhorst, 2006; Thomalla et al., 2006).

7.5.3. Opportunities for Future DRM/CCA Policy and Research

Climate change exacerbates existing disaster and extreme event risk – threatening the stability of already vulnerable communities. And while some of the hazards differ for DRR and CCA, opportunities for closer collaboration exist in both communities. CCA can learn from past DRR experience and local on the ground knowledge, and DRR can learn from CCA community's scientific knowledge. The exchange of information between the DRR and CCA community along with knowledge of past and potential future events can benefit both. This trend is increasing in the literature (Schipper, L. and M. Pelling, 2006; Subbiah, 2008) and within plans and policies in governments at all levels (; Hilhorst, 2003). Commonly, government and institutional departments are separate for CCA and DRR. Research and policy may benefit from closer collaboration - potential opportunities to jointly reduce risk, learn from experience and share knowledge. This opportunity could increase the ability to adapt to climate change and to reduce disaster risk at all levels (van Aalst et al., 2008). DRR commonly works at local and regional levels; adaptation can be advanced by this experience (Vatsa, 2004). There is also the potential to include DRR in CCA policy and research, CCA in DRR policy and research or the creation of new joint policy and research with the explicit agenda of incorporating both (Velasquez, 2008; Wilson and Mcdaniels, 2007). Technology transfer under the UNFCCC – “Increasing options for sharing and mitigating risks and for bundling small-scale projects to bridge the distance between large-scale infrastructure investors and small-scale project and business developers”.

According to ISDR, DRR and CCA share the same ultimate goal of reducing vulnerability to weather and climate hazards. HFA calls on countries to integrate risk reduction measures and climate change adaptation through the following Priorities for Action: 1. Good governance, planning, budgeting and implementing policies to avoid settlement in hazardous areas and ensure that hospitals, schools, and transportation are hazard resistant. 2. Understand the risks we face and take action based on that knowledge. We need to use risk knowledge to develop effective early warning systems. 3. Raise awareness and educate young and old alike so they can reduce their own vulnerability. Many countries are taking such steps through the media and in schools. 4. Changing practices and conditions that aggravate risk, such as environmental degradation and poverty. Protecting precious ecosystems, such as coral reefs and mangrove forests, allows them to act as natural storm barriers. Effective insurance and micro-finance initiatives can help to transfer risks and provide additional resources. 5. Prepare for the disasters that will inevitably strike by having contingency plans in place and emergency funds established, as well as regularly conducting simulation exercises. (UN ISDR 2005a)

Both DRR and CCA have an opportunity to address the underlying risks drivers that increases vulnerability to disaster and extreme events (rural livelihoods, poor urban governance and declining ecosystems that shape the relationship between disaster risk and poverty (Sabates-Wheeler, R. et al., 2008; Few R et al., 2006; UN ISDR, 2009a). A failure to address the underlying risk drivers will result in dramatic increases in disaster risk and associated poverty outcomes. In contrast, if addressing these drivers is given priority, risk can be reduced, human development protected and adaptation to climate change facilitated. Rather than a cost, this should be seen as an investment in building a more secure, stable, sustainable and equitable future.

The inclusion of disasters and risk reduction in the BAP and potentially as a component of the future agreements, lead to an opportunity for the inclusion of CCA in a post-2015, post-HFA, DRR agreement.

7.5.4. Other Relevant Issues and Capacities

7.5.4.1. International Humanitarian Response System

A review of the list of ISDR partner institutions reveals that humanitarian institutions are rapidly growing in numbers at international, national and local levels, often with overlapping mandates and coordination gap among them. It is therefore important to examine how international humanitarian system works in a situation of large and complex emergency which is a likely consequence of climate extremes.

The humanitarian reform system was evolved during 1990s that has stood the test of the time in saving lives and mitigating sufferings during each of the major catastrophic events. The humanitarian response system has coped with these major events and each of these major crises has in its own way tested the humanitarian response system; they have challenged perceptions of humanitarian assistance as impartial, they have challenged the appropriateness of response options and they have challenged the capacity of international and national actors to respond.

Strengthening the capacity of the humanitarian response system at the international and national level is the main reason for humanitarian reform by United Nations in 2006. There are three main elements to the humanitarian reform: 1) to create more predictable humanitarian finances to ensure and enable a prompt response to new or rapidly deteriorating crises; 2) to strengthen response capacity by establishing a system of cluster leads in those areas of activity where there are clearly identified gaps, and finally, 3) to strengthen the Humanitarian Coordinator system to better support field coordination.

7.5.4.2. Relocation or Migration

An extreme form of adaptation is relocation or migration. Relocation calls for a long-term planning and programming at the regional, national and international levels that aims to safeguard the vulnerable people by removing or decreasing their exposure to hazards. For small island states and densely populated low-lying countries like Bangladesh, relocation would eventually lead to a process where people will be obliged to move internationally. movement. Migration adds a fresh perspective to national land-use planning, zoning and relocation plan. A participatory process involving and engaging vulnerable nations is critically important for creation of an effective mechanism to international response.

7.6. Integration Across Scales

At the international level considerable efforts have been made since 1980's to move towards integrated disaster risk reduction. The Hyogo Framework for Action addresses disaster risk reduction with a clear indication of the need to consider climate change related risks (UN ISDR, 2009b). The ultimate objective of the UNFCCC is 'prevention of dangerous human interference with the climate system ' and this matches with both sustainable development and disaster risk reduction perspectives. Further the Bali Action Plan under UNFCCC emphasized the need to link adaptation with DRR. Another major internationally driven policy development is the Millennium Development Goals which are linked to development and poverty reduction and recognize the need for strong linkages with measures that address vulnerability to disasters. However, the international legal status of the UNFCCC, the HFA and the MDGs are not identical.

These three main policy frameworks continue to operate parallel to each other resulting in uncoordinated actions and duplication (Yamin et al., 2005; O'Brien et al., 2006; Thomalla et al., 2006). There are powerful legal, institutional and political obstacles that make it difficult for e.g. for disaster relief to be more development orientated or for it to shift from a reactive approach to disaster as opposed to a disaster risk reduction framework. For example, many decision makers respond more to actual disasters than to the need for DRR (Pelling 2006).

Addressing vulnerabilities has been in the hands of an array of national, regional and international institutions often with weak or no legal mandates and without an authoritative position either to command nor easily to achieve major changes for creating a resilient society. For example in practice, during reconstruction periods, after a disaster, few of the main actors make a deliberate effort to consider MDGs (Schipper and Pelling, 2006). Cases where development contributes to vulnerability e.g. – through carbon-intensive developmental pathways and through a variety of socio-economic and political actions are numerous and account for the currently observed climate change and partly to the failure to meet the MDGs (Pelling, 2006).

Some experts point to the need to devise a joint overarching objective that can synthesize both the concerns and interests of vulnerability reduction, for climate change, development and disaster relief communities, and through the respective policies which they ean espouse.. This will reinforce their individual efforts, while also multiplying, their combined contributions, achieving more effective use of resources in the process (Schipper and Pelling, 2006).

Covariate and potentially very large and irreversible risks associated with climate change imply a need for integration of policies across scale and which they require a higher level of international collaboration to a scale not yet achieved. To fully address climate related disaster risks, international cooperation may well need to extend to wider considerations such as labour matters and resulting migration flows or trade and economic policies. Additional consequences also would be manifested in food and financial markets, insurance calculations, peace-keeping and technology and in the array of research and development possibilities.

In 2001, the IPCC was able to conclude "Climate change does not in itself stimulate development of new DRR or CCA strategies but it encourages a more adaptive, incremental, risk-based approach to both the reduction of disaster risk and adaptation to climate change. More precisely, it provides further encouragement for a trend that is already gathering pace"(IPCC. TAR. WG II p. 227 2001). Since that time DRM and CCA have clearly gained in momentum but arguably as shown in this chapter fall short of demonstrated and acknowledged needs.

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Table 7-1: International frameworks and typical strategies to manage risks.

INTERNATIONAL FRAMEWORKS AND TYPICAL *STRATEGIES* TO MANAGE RISKS			
	International Frameworks		
Strategies for Reducing Risks	**Disaster Risk Management (DRM) including the Hyogo Framework for Action (HFA)**	**United Nations Convention for Climate Change (UNFCCC)**	**Other International Frameworks**
Through Non-Structural Measures	- *The Integration of DRR into sustainable development policies and planning.* ***(HFA Strategic Goal)*** - *The development and strengthening of institutions, mechanisms and capacities to build resilience to hazards.* ***(HFA Strategic Goal)*** - *Ensure that disaster risk reduction (DRR) is a national and local priority with a strong institutional basis for implementation* ***(HFA Priority for Action)*** - *DRR institutional mechanisms(national platforms) designated responsibilities* ***(HFA Key Activity)*** - *Use knowledge, innovation and education to build a culture of safety and resilience at all levels* ***(HFA Priority for Action)*** - *Networks across disciplines and regions; dialogue* ***(HFA Key Activity)*** - *Mobilise resources and capabilities of relevant national, regional and international bodies, including the UN System* ***(HFA Resource Mobilisation: States, Regional and International Organisations)*** - *Provide and support the implementation of the HFA in disaster prone developing countries, including through financial and technical assistance, addressing debt sustainability, technology transfer, public-private partnership and North-South and South-South cooperation* ***(HFA Resource Mobilisation: States, Regional and International Organisations)*** - *MainstreamDRR measures into multilateral and bilateral development assistance programmes* ***(HFA Resource Mobilisation:***	[To be completed]	- *UN Agencies supporting the Millennium Development Goals (MDG)* - *The United Nations Development Assistance Framework* - *International International Organisations promoting ISO Standards* - *World Trade Organisation (WTO)* - *WHO and other International Health Organisations who promote International Health Regulations* - *International Humanitarian, Rights organisations who promote Internation Human Rights and Refugee Law* - *The Red Cross Code of Conduct* - *International support for the Mauritius Strategy for the Sustainable Development of Small Island Developing States*

	States, Regional and International Organisations)		
Through Structural Measures	- *The systematic incorporation of risk reduction approaches into the implementation of emergency preparedness, response and recovery programmes.* ***(HFA Strategic Goal)*** - *Identify, assess and monitor disaster risks and enhance early warning.* ***(HFA Priority for Action)*** - *Early warning: people centred; information systems; public policy* ***(HFA Key Activity)*** - *Scientific and technological development; data sharing, space based earth observation, climate modeling and forecasting ; early warning* ***(HFA Key Activity)*** - *Regional and emerging risks (HFA Key Activity)* - *Sustainable ecosystems and environmental management* ***(HFA Key Activity)*** - *Regional approaches to disaster response, with risk reduction focus* ***(HFA Key Activity)***	[To be completed]	- *UN Agencies supporting the Millennium Development Goals (MDG)* - *The United Nations Development Assistance Framework* - *International Organisations promoting ISO Standards* - *International support for the Mauritius Strategy for the Sustainable Development of Small Island Developing States* - *The Red Cross Code of Conduct*
Through Risks Sharing/ Transfer	- *Develop partnerships to implement schemes that share, pool and transfer risks; improve affordability and accessibility of these schemes to the most vulnerable* - *Promote an environment that encourages a culture of insurance in developing countries* ***(HFA Resource Mobilisation: States, Regional and International Organisations)*** - *Financial risk-sharing mechanisms (HFA Key Activity)*	[To be completed]	***Diarmid*** ***Can you, (with some creative imagination!) relate any of these frameworks to risk transfer strategies?***

Notes:
1. Due to the large number of actors involved in international risk management/ risk reduction, collective descriptions are noted in this table, rather than attempting to list individual organizations
2. The strategies noted on this table are all those that require international, rather than merely national action. These strategies are undertaken by international actors working in partnerships with national governments and institutions

Table 7-2: International frameworks and typical actors who manage risks.

INTERNATIONAL FRAMEWORKS AND TYPICAL *ACTORS* WHO MANAGE RISKS			
Actors who Manage Risks	**International Frameworks**		
	Disaster Risk Management (DRM) including the Hyogo Framework for Action (HFA)	**United Nations Convention for Climate Change (UNFCCC)**	**Other International Frameworks**
Through Non-Structural Measures	• *Governments* • *Regional Intergovernmental Organisations* • *UN System* • *Other International Organisations* • *International Financial Institutions (IFI's)* • *Non-Governmental Organisations* • *Private Sector* • *Media* • *Academic Institutions*	***[to be completed]***	• *UN Agencies (supporting the Millennium Development Goals) (MDG)* • *The United Nations Development Assistance Framework* • *International Organisations (promoting ISO Standards)* • *World Trade Organisation (WTO)* • *WHO and other International Health Organisations (who promote International Health Regulations)* • *International Humanitarian, Rights organisations (who promote Internation Human Rights and Refugee Law)* • *The Red Cross and other International NGO's (who support the Code of Conduct)* • *International support (for the Mauritius Strategy for the Sustainable Development of Small Island Developing States)*
Through Structural Measures	• *Governments* • *Regional Intergovernmental Organisations* • *UN System* • *Other International Organisations* • *International Financial Institutions (IFI's)* • *Non-Governmental Organisations* • *Private Sector* • *Media* • *Academic Institutions*	***[To be completed]***	• *UN Agencies (supporting the Millennium Development Goals) (MDG)* • *The United Nations Development Assistance Framework* • International Organisations (promoting ISO Standards) • World Trade Organisation (WTO) • *WHO and other International Health Organisations (who promote International Health Regulations)* • *International Humanitarian, Rights organisations (who promote Internation Human Rights and Refugee Law)* • *The Red Cross and other IOnternational NGO's (who support the Code of Conduct)* • *International support (for the Mauritius Strategy for the Sustainable*

			Development of Small Island Developing States)
Through Risk Sharing/ Transfer	- *International Financial Institutions (IFI's)* - *Insurance and Re-Insurance companies* - *Development organizations* - *International NGO's*	***[To be completed]***	- *The Hyogo Framework and the Bali Action Plan both mention Risk Sharing and Transfer* - *UNFCCC and the Kyoto Protocol both mention considerations of insurance instruments*
Notes: 1. Due to the large number of actors involved in international risk reduction, collective descriptions are noted in this table, rather than attempting to list individual organizations. 2. All the actors noted on this table perform international, roles, normally working in partnerships with national governments and institutions			

Table 7-3: Linkages of MDGs to DRM and CCA.

Goal	**Negative impact of extreme events on MDG achievement**	**Benefits of MDG achievement for DRM and CCA**
Eradicate extreme poverty and hunger	Impact on livelihood sustainability, food security Indirect impacts on macroeconomic growth and social support	Increased socioeconomic resilience (ability to buy goods and services following extreme events) Increased biological resilience (resistance to disease during famine)
Achieve universal primary education	Damage to educational infrastructure, Population displacement and the occupation of schools Reduction in household assets, more need for children to work rather than attend school	Improved ability to participate in community-based DRM activities
Promote gender equality and empower women	Higher female mortality in some extreme events Greater workloads and lower food entitlements after disasters. Social disruption leading to exposure to sexual violence Potential reinforcement of power inequalities between men and women	Potential for more equitable and effective DRR through empowerment of women to participate in or lead community based action (e.g. from Latin America).
Reduce child mortality	Increased hazards to which children are particularly vulnerable (heat stress, physical injury in storms and floods, food insecurity). Potential for disasters to exacerbate other socioeconomic determinants of child health (e.g. extreme poverty, armed conflict and infectious disease).	Enhanced population resilience to extreme events Enhanced motivation for long-term sustainable planning, including family planning
Improve maternal health	Damage to health infrastructure Shocks, stresses and erosion of household assets for pregnant women	More resilient maternal health infrastructure and practice reduces vulnerability to extremes
Combat HIV/AIDS, malaria and other diseases	Enhanced transmission of environmentally mediated diseases, such as diarrhoea and malaria, in some circumstances Loss of livelihood and population displacement leading to higher-risk sexual behaviour. Food insecurity leading to decreased immunity to infectious disease	Increased human resource capacity within health, emergency and other services (healthier staff) Reduced competition for scarce resources (less effort diverted to treating disease)
Ensure environmental sustainability	Physical damages to aquatic and land-based ecosystems. Damages to infrastructure for managing environmental health risks (e.g. water and sanitation infrastructure)	Enhanced ecosystem service of protection from natural disasters (e.g. flood protection and water filtration) Less extreme climate change, and associated hazards
Develop a Global Partnership for Development	Inequitable damages to least developed countries, particularly those with high physical exposure (e.g. small island develops states)	More equitable and efficient burden sharing between developed and developing countries.

Adapted from Schipper and Pelling (2006).

Table 7-4: Annual adaptation costs in developing countries.

	Assessment Year	USD (Billion)	Time Frame
UNDP	2007	86	2015
UNFCCC	2007	28-67	2030
OXFAM	2007	50	Present
World Bank	2007	9-41	Present

Sources: Human Development Report, UNDP (2007); Economic Aspects of Adaptation to Climate Change: Costs, Benefits, and Policy Instruments, OECD (2008)

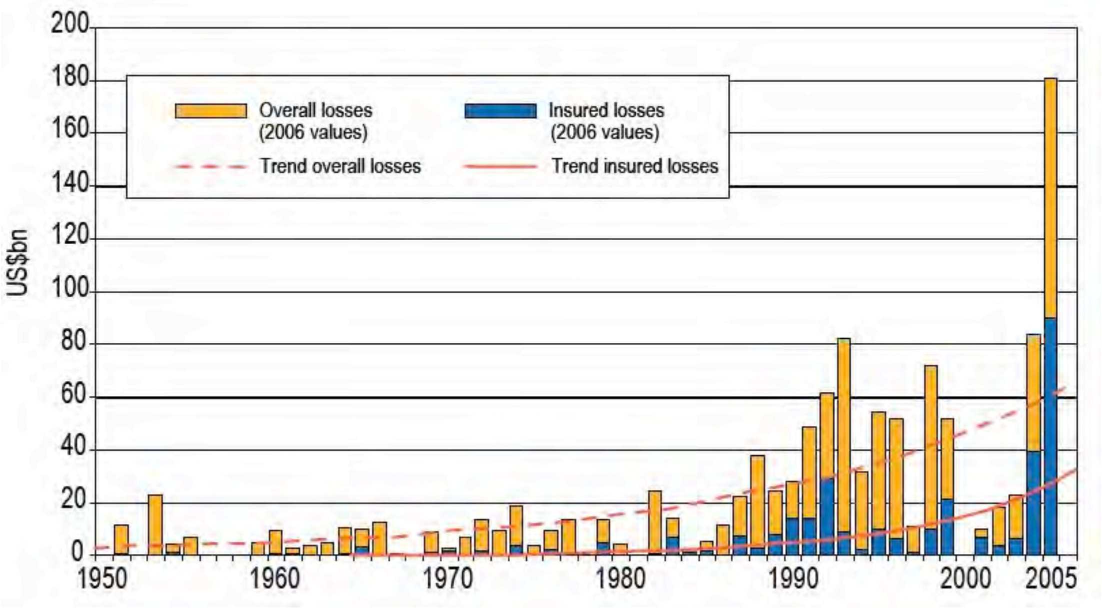

Figure 7-1: Overall and insured losses from great natural catastrophes, 1950-2006 (Munich-Re, 2007).

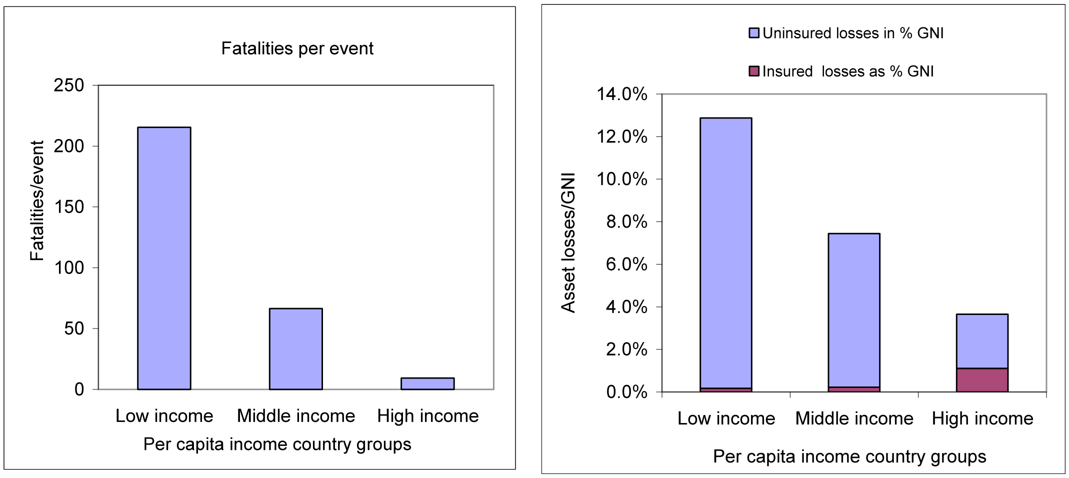

Figure 7-2: Differential burden of natural disasters according to country income groups (Linnerooth-Bayer et al., 2010; based on data from Munich Re, 2005) (Note: country income groups according to World Bank classification).

Chapter 8. Toward a Sustainable and Resilient Future

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References

Executive Summary

Realizing adaptation potentials requires (a) **anticipation** of vulnerabilities and (b) **anticipatory actions** to reduce those vulnerabilities, rooted in risk management perspectives and development co-benefits.

It is unlikely that societies will be able to adapt to climate extremes associated with rapid and severe climate change without transformational changes. The risks associated with severe climate change may create **complex emergencies and new types of disasters**, potentially leading to risks and losses that threaten the sustainability of current patterns of activity.

Natural risks and climate change are some of the stresses that affect societies and economies. Managing these issues without taking into account other stresses (e.g., pressure on land availability, socio-economic trends, financial constraints) may lead to suboptimal strategies and **trade-offs**. In particular, in absence of multi-stress analyses, measures implemented to reduce one risk can **enhance other stresses**.

Managing the risks associated with **frequently occurring low-intensity events** is an effective **here and now** strategy to adapt development to climate change and will reduce the impact of future extremes. However, it is necessary to ensure that current risk reduction measures do not exacerbate current or future vulnerability.

Choices and outcomes for adaptive actions to climate extremes and extreme events are complicated by **multiple interacting processes**, competing prioritized **values** and **objectives**, and **different visions of development**.

A common key challenge to both disaster risk reduction and climate change adaptation is to strengthen **institutions** and **governance** arrangements (and create synergies across scales) and to increase access to information, technology, resources and capacity in countries and localities with the highest climate related risks and weak capacities to manage those risks.

A key challenge is to address and incorporate **uncertainty** into planning and implementing response. **Adaptive risk management** strategies are helpful in responding in the presence of uncertainty and complexity.

There is no single approach, framework or pathway to a sustainable and resilient future; a **diversity** of **responses** to extremes taken in the present can contribute to future resilience in situations of uncertainty.

Disasters can be considered both a **problem of development**, and a **problem for development**. Disaster risk reduction and climate change adaptation strategies must address both underlying problems of development, and emerging implications for development.

8.1. Introduction

Changes in the frequency, timing, magnitude, and characteristics of extreme events pose challenges to disaster risk reduction and climate change adaptation, both in the present and in the future. Many of these challenges were discussed in the previous chapters of this report, including the scientific, conceptual, political and practical hurdles that must be acknowledged and overcome. It is clear from the assessment presented in these chapters that there are multiple perspectives on disaster risk reduction and climate change adaptation, and diverse interpretations of the problems and the solutions. Consequently, there are many entry-points for action, often involving tensions and trade-offs with multiple policy goals, particularly in relation to decision-making under uncertainty.

The complex interactions among changes in average climate conditions, changing occurrences of frequent, low-magnitude events and infrequent, high magnitude events pose challenges to sustainability and resilience, as they influence not only lives and livelihoods, but development trajectories. Changes in extreme events associated with climate change add additional risk and uncertainty to decision-making in the context of multiple stressors. However, for many population groups, regions, or sectors, there is no clear distinction between ongoing climate variability and changing extremes. Furthermore, extremes are translated into impacts by the underlying conditions of risk associated with the contexts in which they occur. Because climate change is only one of the many processes affecting people and places (and often not the most important), responses to multiple interacting stressors and risks require an understanding of these contexts, and of how people make choices. For example, choices can be associated with proximity to livelihood options, amenity values, cultural factors, risk perception, and so on. Looking at contexts and choices leads to a better understanding of how choices are constrained or facilitated by social, economic, political, technological and environmental conditions.

This chapter assesses a broad literature presenting insights on how diverse understandings and perspectives on disaster risk reduction and climate change adaptation can promote a more sustainable and resilient future. Both disaster risk reduction and climate change adaptation are closely linked to development processes. A key point emphasized throughout this chapter is that changes in extreme events call for greater alignment between climate change responses and sustainable development strategies, but that this alignment depends on greater coherence between short-term and long-term objectives. Research on the resilience of social-ecological systems provides some lessons for addressing the gap between these objectives. Yet strengthening the links between disaster risk reduction, climate change adaptation and sustainable development will not be unproblematic, as there are different interpretations of development, different preferences, prioritized values and motivations, different visions for the future, and many trade-offs involved.

The changes in extreme event frequency and intensity associated with climate change can to some extent be managed as part of larger efforts to reduce anthropogenic climate change through reduction in greenhouse gas emissions. More importantly, however, the drivers of disaster risk can be addressed as a way not only to reduce the losses associated with climate extremes, but as a way of facilitating social and economic welfare and resilience. The challenges posed by climate extremes can provide additional impetus to address existing disaster risks, creating positive outcomes for humans and the environment. A growing literature suggests that a resilient and sustainable future is a choice that involves proactive measures including learning, innovation, transition, and transformation. Although such measures may be interpreted as wishful thinking, technological and managerial optimism, naive “green” rhetoric, or utopianism, there is a growing scientific and popular literature that discusses how climate change responses can lead to transformative social, economic, and environmental changes (Loorbach et al., 2008; Hedrén and Linnér, 2009).

While positive and optimistic outcomes are possible, they are far from inevitable. Global risk assessments show that the social and economic losses already associated with climate extremes are disproportionately concentrated in developing countries, and within these countries in poorer communities and households (ISDR, 2009). Clearly the potential for concatenated global impacts of extreme events continues to grow as the world’s economy becomes more interconnected, but most impacts will occur in contexts with severe environmental, economic, technological, cultural, and cognitive limitations to adaptation. A reduction in the risks associated with climate extremes is therefore a question of political choice, which involves addressing issues of equity, rights and access at all levels. These choices will be made by different institutions and actors, and may open new debates about rights and responsibilities between governments, local authorities, the private sector, civil society, and individuals, at different scales.

There is a growing literature from the physical, social and humanistic sciences to support the conclusion that rapid and extreme climate change poses serious threats to society, which are likely to be felt through tipping points, complex emergencies and new types of disasters (Lenton et al., 2008, Rockström et al., 2009). While this chapter shows that a resilient and sustainable future is possible, these outcomes become increasingly less likely as the magnitude of climate change increases. Indeed, with more rapid climate change, adapting becomes more difficult and success in doing so becomes less likely (Dessai et al., 2009a; Dessai et al., 2009b; Hallegatte, 2009; Oswald Spring and Brauch, 2010). In addition, as shown by many of the case studies in Chapter 9, the consequences of non-adaptation or maladaptation increase with the pace and amplitude of climate change. It is clear that adaptation and disaster risk management can be improved, but that responses will be seriously challenged by relatively severe climate change and associated extremes. The chapter concludes by identifying and assessing synergies for action that address the tensions between different preferences and visions, which may be considered a prerequisite for responding to multiple and interacting challenges. Disaster risk reduction and climate change adaptation are both key aspects of development, development planning, and human development in general, and thus can be seen as cornerstones for a resilient and sustainable future.

8.2. Disaster Risk Reduction as Adaptation: Relationship to Sustainable Development Planning

Earlier chapters discussed the concepts of and relationship between disaster risk reduction and climate change adaptation. Disaster risk reduction is increasingly seen as one of the "frontlines" of adaptation, and perhaps one of the most promising contexts for mainstreaming or integrating climate change adaptation into sustainable development planning. This gains added importance, given that many of the impacts of current and future climate change will be experienced through extreme weather events (Burton et al., 2002). However, contested notions of development and hence differing perspectives on sustainable development planning lead to different conclusions about how disaster risk reduction can contribute to adaptation. This section reviews the definitions of some of the key concepts used in this chapter, and considers how different prioritized values, ways of approaching the future, and technology can influence sustainable development.

8.2.1. Concepts of Adaptation, Disaster Risk Reduction, and Sustainable Development and How They are Related

Adaptation to climate change has been defined as adjustments to reduce vulnerability or enhance resilience in response to observed or expected changes in climate and associated extreme weather events (IPCC, 2007). Adaptation involves changes in social and environmental processes, practices and functions to reduce potential damages or to realise new opportunities. It also involves changes in perceptions of climate risk (Weber, 2010). Adaptation actions may be anticipatory or reactive and may be undertaken by public or private actors. In practice, adaptation is more than a set of discrete measures specifically to address climate change, but an on-going process that encompasses responses to many factors and stresses (Tschakert and Dietrich, 2010). Actions to adapt to climate change are often difficult to distinguish from development actions, as in many cases adaptations yield development co-benefits (Agrawala, 2005; Klein et al., 2007; McGray et al., 2007; Hallegatte, 2008).

Disaster risk can be defined in many ways (see Chapter 1). In general, however, it is closely associated with the concepts of exposure, vulnerability, and hazards. All three of these concepts are interlinked, and vary and change over time. Consequently, disaster risk is not static, but rather a reflection of dynamic biogeophysical and socio-economic conditions. Taking risks is unavoidable and can be desirable if the benefits from the actions that create or increase risks yield other benefits that exceed the negative impact of risks. For instance, building in low-lying coastal zone can be considered beneficial in spite of the corresponding increase in risk, if the economic activity (e.g., ports and tourism) and the jobs it creates are highly valued by the population and the decision-makers (see for instance on the case of New Orleans, Lewis, 2003; Hallegatte, 2006; Levina et al., 2007). As a consequence, reducing risk as much as possible may not always be desirable, and analyses of the cost and benefits of risks are necessary to inform decision-makers.

Global increases in disaster risk since 1990 have been fundamentally driven by the increasing exposure of people and economic assets. The population exposed to major river basin flooding is estimated to have increased by 28% from 1990 to 2007 while the exposure of economic assets had increased by 98% (ISDR, 2009, P.52). Estimates also indicate that growing exposure will play a major role in shaping future risk to climate extremes (Economics of Climate Adaptation Group, 2009 : 40 -41). These increases in exposure are reflections of global patterns and trends of urban and economic development (Satterthwaite, 2007). For example, rates of urbanization generally correspond to increases in the percentage of GDP concentrated in the industry and service sectors. In some parts of the world, therefore, increases in disaster risk are associated with economically successful cities. For example, coastal cities in the export-led economies of Asia may have large populations exposed to hazards such as flooding, cyclones and storm surges (Nicholls et al., 2008). However, disaster risk is also growing in less successful cities. For example, in sub-Saharan Africa, some cities are experiencing increases in both vulnerability and exposure, particularly those with more than 70% of their population living in informal settlements, which are often in hazard prone areas and without risk-reducing infrastructure such as drainage (Dodman, Hardoy, Satterthwaite, 2008; Diagne and Ndiaye, 2009; Songsore, et. al. 2009).

While the disaster risks associated with low-recurrence extreme events capture the headlines, a significant proportion of damage is associated with frequently occurring, low-intensity, localized hazards (ISDR, 2009, P.67). This damage is particularly concentrated in low-income groups and contributes to increases in poverty, inequality and declining human development indicators (ISDR, 2009 : 78 – 84). Global models of disaster risk associated with weather-related hazards potentially influenced by climate change, show how risk is disproportionately concentrated in developing countries (ISDR, 2009). For example, in the case of tropical cyclones, relative mortality risk has been calculated as 200 times greater in low income countries than in OECD countries (ISDR 2009). In the case of relative economic loss, expressed as a proportion of exposed GDP, estimated losses in East Asia and the Pacific, Latin America and the Caribbean and South Asia are between 5 and 7 times greater than in OECD countries (ISDR 2009). Small-island states and others with small and vulnerable economies experiencing extreme trade limitations are particularly at risk (Corrales et. al. 2008). At the same time, increasingly global capital flows, as well as the increasing exposure of financial markets to risk (through the growth of insurance linked securities), increase the potential for impacts far beyond the areas where hazards occur. Ultimately, disaster risk is a global responsibility that all countries share.

Exposure of people, species and economic assets to hazards is a function of both physical geography and the social and economic context in which hazards occur. The social and economic context plays a major and increasing role as human populations increasingly settle in vulnerable areas (Pielke et al., 2008), and as globalization processes create new types of exposure (Leichenko and O'Brien, 2008; Stiglitz 2002, 2010). An increasing number of people are exposed to hazards as a result of ongoing development inequalities (for example, inadequate access to basic needs) and governance weaknesses (for example, insufficient land-use and building control) manifest through changes in the quality, density and distribution of basic needs and human rights as well as risk management-specific capacities (UNDP, 2004; ISDR, 2009). Rapid and uncontrolled urbanization may also increase exposure, especially in developing countries (Nicholls et al., 2008). Increases in exposure are due to important underlying factors, such as the growth of export-led economies in Asia that drives development in port cities vulnerable to storm surges, or the industrialization of developing countries that leads to rapid urbanization in land-scarce areas. Increases in exposure have contributed significantly to increases in vulnerability and disaster risk (Pielke et al., 2008; ISDR, 2009 and 2009 Swiss Re. report on Economics of Adaptation). For example, coastal cities in regions of tropical cyclone incidence have increased rapidly in both size and population over the past thirty years, exposing many more people to typhoons and storm surges (references).

Vulnerability has many different (and often conflicting) definitions and interpretations, both across and within the disaster risk and climate communities (see Chapter 2). In the risk management community, it is often considered the propensity or susceptibility of people or assets exposed to hazards to suffer loss, which may be closely associated with a range of physical, social, cultural, environmental, institutional and political characteristics (Lavell, 2009, P.14). In the climate change community (IPCC, 2007), vulnerability is a much more integrated concept, combining hazard, exposure, risk-management, and adaptive capacity (Fussel and Klein, 2006). Vulnerability can increase or decrease over time, as the result of both environmental and socioeconomic changes. In general, improvements in a country's development indicators have been associated with reduced vulnerability (Strobl and Schumacher, 2008). As countries develop, there is often a reduction in human mortality, yet an increase in economic loss and insurance claims (ISDR, 2009 and 2009 Swiss Re. report on Economics of Adaptation, Pielke met al. 2008; EM-DAT reports; etc.). However, some types of development may increase vulnerability, particularly if it leads to social marginalization for some groups, to a degradation of ecosystem services, or to uncontrolled urbanization (references). Vulnerability increases for many when development gains are unequally spread, particularly when large populations (often the majority of the urban population) live in unsafe dwellings or environments. Even where growth is more equitable, risk can be generated, for example when modern buildings are not constructed to prescribed safety standards.

Hazards consist of physical phenomena such as floods, landslides, cyclones, drought or wildfires that are potentially dangerous (to the exposed elements). Hazards are changing, not only as the result of climate change, but also due to human activities. For example, hazards associated with floods, landslides, storm surges and fires are influenced by declines in regulatory ecosystem services; the drainage of wetlands, deforestation, the destruction of mangroves and the changes associated with urban development (such as the impermeability of surfaces and overexploitation of groundwater) are all factors that modify hazard patterns (Millenium Ecosystem Assessment, 2005; Nicholls et al., 2008). Indeed, most weather-related hazards now have an anthropogenic element (Lavell, 1999, Cardona, 1996).

Climate change magnifies present ongoing risk patterns, through changes in the frequency, severity and spatial distribution of weather-related hazards, as well as through increases in vulnerability due to changing climate means. Disaster risk reduction, by addressing existing risks and the underlying risk drivers, can be considered key to climate change adaptation. Promoting disaster risk reduction as a means for adaptation opens great scope for advancing practices in both fields. For example, disaster risk reduction promotes planning for multi-hazard contexts (including non-climate related issues such as economic underdevelopment, poverty, marginalization, etc.). Whereas climate change policy has tended to approach risk and its management from a top-down, global or at least national viewpoint (e.g., through reduction of greenhouse gas emissions), disaster risk reduction, including response and reconstruction and climate change adaptation are driven more by a bottom-up focus that emphasizes the contingency of geography and history in shaping risk and coping capacity (Schipper and Pelling, 2006; McBean and Ajibade, 2009; Pelling and Schipper, 2009).

Risk is linked to hazards, exposure and vulnerability, and disaster risk reduction can in principle address any combination of these three. For example, the hazard associated with tropical cyclones can be reduced by ecosystem measures such as conserving mangroves and by improving drainage; exposure can be reduced through zoning and land-use control; physical vulnerability can be reduced through improving building codes while early warning systems, disaster preparedness plans and education programs can reduce social vulnerability. Disaster risk reduction may be anticipatory (ensuring that new development does not increase risk) or corrective (reducing existing risk levels) (Lavell, 2009: 19). Given expected increases in the population of cities in hazard prone areas, anticipatory disaster risk reduction is clearly fundamental to reducing the risk to future climate extremes. At the same time, investments in corrective disaster risk reduction are required to address the huge accumulation of existing climate risks.

A significant proportion of risk in developing countries is concentrated in informal urban settlements. Currently it is estimated that more than 1 billion people live is such settlements and that the number is growing by about 25 million people a year (UN Habitat, 2009). Not all informal settlements are located in hazard prone areas, but often the most hazard prone areas in cities are occupied by informal settlements. In cities where detailed data is available, such as San Jose, Cali and Caracas (Bonilla, 2008; Jimenez, 2008), the increase in disaster loss is closely correlated with the expansion of informal settlements. Such areas are characterised by high levels of relative poverty and everyday risk, due to water stress, poor sanitation, dangerous living and working environments, pollution and other factors, with mortality rates for children under the age of five that may be 10 – 15 times higher than in cities in high income countries (Satterthwaite, Dodman, Hardoy, 2008).

Risk is a symptom of a generalised failure of development planning, but also governance. For example, with a few notable exceptions, most city governments in developing countries have not been able to provide land for the urban poor, meaning that they have to occupy land with the lowest value, often in hazard-prone areas (references). Secondly, most city governments have been unwilling or unable to provide the necessary infrastructure and services, including drainage (see Bhagat et al., 2006; Gupta, 2007; Ranger et al., 2010). Disaster risk management and adaptation in urban areas is thus fundamentally associated with the challenge of improving urban governance. Improvements in the provision of municipal services such as water, electricity, public health etc. do not *per se* reduce disaster risk. However it is unlikely that urban governments that are unable or unwilling to address the issue of access to land, infrastructure and services for poorer households will be able to address disaster risk.

In practice, particularly in the developing countries, disaster risk reduction has remained challenging and out of reach. A recent self-assessment in progress by 102 countries against the objectives of the Hyogo Framework of Action (ISDR, 2009:119-137) indicates that few developing countries have comprehensive, accurate and accessible risk assessments, which are a pre-requisite for both anticipatory and corrective disaster risk reduction. Above all, even when risk information is available, the institutional, legislative and political frameworks existing for disaster risk reduction do not facilitate the use of the information in development planning and decision making (Lavell and Franco, 1996; UNDP, 2008, ISDR, 2009:119-137). These frameworks are often centred in emergency response organizations that lack political authority. Implementation and enforcement mechanisms are often weak, particularly in countries where a large proportion of economic activity occurs in the informal sector. There is little or no integration between the frameworks developed for disaster reduction, climate change adaptation, and poverty reduction and development in general. As a result, disaster risk reduction is often limited to improvements in early warning, preparedness and response. While these actions can be decisive in reducing mortality risk, they do not address the underlying drivers of risk mentioned above, meaning that risk levels continue to rise unchecked. Likewise, there are limited examples of successful climate change adaptations in the literature (Fankhauser et al., 1999; Adger et al. 2007, Repetto, 2009), although attention to adaptation and its links to sustainable development is growing (Bizikova et al. 2010; Eriksen et al. submitted).

Sustainable development has become part of climate change policy discussions at the global level, particularly due to adoption of Agenda 21 and the various conventions resulting from the UNCED-1992 (Cohen et al., 1998, Yohe et al., 2007). It is an integrating concept that embraces economic, social and environmental issues (WCED, 1987; Grist, 2008). The generally accepted and most widespread definition comes from the Brundtland Commission Report, which defined sustainable development as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (WCED, 1987). Hence sustainable development does not preclude the use of exhaustible natural resources, but requires that any use be appropriately managed or offset. Some argue that sustainable development cannot be achieved without significant economic growth in the developing countries, while others argue that any interpretations of development focusing on continued economic growth built on ever increasing rates of extraction and consumption of material goods directly contradicts notions of sustainability (Redclift, 1992; Goldemberg, et al., 1995; Robinson, 2004; Harvey, 2010). Questions of how sustainable economic growth is to be achieved, and the consequences for the spatial and temporal distribution of benefits and costs derived from resource use, consumption and impacts on increasingly fragile ecological systems, lie at the heart of challenges for moving towards sustainable development in a context of climate change.

The mainstream sustainable development discourse typically emphasizes inter-generational equity issues and focuses on both global and local environmental problems. Inter-species considerations are reduced to concerns for biodiversity depletion and ecosystem services (Lumley and Armstrong, 2004**;** Grist, 2008). Despite the centrality of sustainable development in climate change adaptation and disaster risk management policy and its function as an integrating concept, sustainable development inevitably draws attention to conflicting interpretations of ‘development’ (Redclift, 1992). Although it is clear that ‘development’ can be risk-reducing or risk-increasing (urbanization in coastal areas may increase disaster risk, while improved education, housing, and access to health may reduce disaster risk), it is important to recognize that the concept of development itself has been used in many ways. Although the dominant international discourse on development focuses on economic growth (Harvey, 2010), particularly through market-based policies, the concept of development has been used very differently by many scholars in the South (Amin, 1990, 1997; Stavenhagen, 2004; Furtado, 1965; Marini, 1973; Sen, 1992, 1999; Kameri-Mbote and Anyango Oduor, 2008; Huq et al., 1995; Huq and Asaduzzaman, 1999; Illich, 1976, 1976a; Freire, 1970, 1974, 1998, 1998a). Many scholars, for example, have examined the development of underdevelopment (Strahm and Oswald, 1990), including how ‘development’ in some regions has historically increased vulnerability to climate variability, as for example when local natural capital is extracted and economic capital accrues elsewhere, as in the case of droughts in India during the 19th century which were tied to British colonial extractive tendencies (Davis, 2001).

8.2.2. The Role of Values and Perceptions in Shaping Response

Planning for a future with heightened uncertainty when the stakes are high creates tensions among different visions of development. The disaster risk reduction community has used several points of view for resolving decisions in where to invest scare resources. These points of view include, for example, considerations of moral obligation and economic rationality (Sen, 2000). This inevitably draws attention to role of values, and in particular to how different ways of perceiving climate change and disaster risk lead to different prioritized solutions. Values describe what is desirable or preferable, and they can be used to represent the subjective, intangible dimensions of the material and nonmaterial world (O'Brien and Wolf, 2010). Values often inform action, judgment, choice, attitude, evaluation, argument, exhortation, rationalization, and attribution of causality (Rokeach 1979). Recognizing and reconciling conflicting values increases the need for inclusiveness in decision-making and for finding ways to communicate across social and professional boundaries.

Values are closely linked to worldviews and beliefs, including perceptions of change and causality (Rohan 2007; Leiserowitz 2006; Weber 2010). Losses from extreme events can have implications beyond the objective, measurable impacts such as loss of lives, damage to infrastructure, or economic costs. They can lead to a loss of what matters to individuals, communities, and groups, including the loss of a sense of place, loss of identity, or loss of culture. This has long been observed within the disaster risk community (Hewitt, 1997; Mustafa, 2005) and in more recent work by climate change community (O'Brien, 2009; Adger et al., 2010). A values-based approach recognizes that socio-economic systems are continually evolving, driven by innovations, aspirations and changing values and preferences of the constituents (Simmie and Martin, 2010). Such an approach raises not only the ethical question of 'Whose values count?', but also the important political question of 'Who decides?'. These questions have been asked both in relation to disaster risk (Blaikie et al, 1994; Wisner, 2003; Wisner et al, 2004) and to climate change (Adger 2004; Adger et al. 2010; O'Brien and Wolf, 2010), and are significant when considering the interaction of climate change and disaster risk (Pelling, 2003).

The ethical considerations associated with disaster risk reduction and climate change adaptation are increasingly discussed in the literature (Gardiner 2010, references). Moral obligation to reduce avoidable risk and contain loss has been recognised in the UN Universal Declaration of Human Rights since 1948: Article 3 provides for the right to 'life, liberty and security of person', while Article 25 protects 'a standard of living adequate for the health and well-being... in the event of unemployment, sickness, disability, widowhood, or old age or other lack of livelihood in circumstances beyond his [sic] control'. The humanitarian community, and civil society more broadly has made most progress in meeting these aspirations (Kent, 2001), perhaps best exemplified by The Sphere standards. These are a set of self-imposed guidelines for good humanitarian practices that require impartiality in post-disaster actions including shelter management, access and distribution to relief and reconstruction aid. The ethics of risk management have also been explored in adaptation through the application of Rawls' theory of justice (Rawls 1971). This logic argues that priority be given to reducing risk for the most vulnerable even if this limits the numbers who can be raised from positions of vulnerability (Grasso, 2009, 2010; Paavola, 2005; Paavola and Adger 2006, Paavola et al, 2006). This is in contrast to the approach broadly taken in meeting the MDGs, where global targets encourage support for the number of people to meet each standard rather than focussing on the most excluded or economically poor.

Economic rationality argues for investing in risk reduction where it is most cost-effective, and where calculated economic benefits are perceived to exceed costs. The calculated benefits of investing in risk reduction vary (e.g. from DFID), but are often considered significant (see Ghesquiere et al., 2006; World Bank 2010). There are, however, extreme difficulties to account for the complexity of disaster costs, i.e. of risk reduction investment benefits. The probabilistic risk assessments that form the basis for current models of cost-benefit analysis, rarely take into account the extensive risks that account for a substantial proportion of disaster damage for poorer households and communities (Marulanda, Cardona, and Barbat, 2010; ISDR, 2009, ISDR, 2002). At the same time, outcomes such as increased poverty and inequality (Fuente and Dercan, 2008), health effects (Murray et al., 1996; Grubb et al. 1999; Viscusi et al, 2003), cultural assets and historical building losses (ICOMOS, 1993), environmental impacts, and distributive impacts (Hallegatte, 2006) are very difficult to measure in monetary terms.

Disasters often require urgent action and represent a time when everyday processes for decision-making are disrupted. Often, the most vulnerable to hazards are left out of decision-making processes (Mercer et al, 2008; Pelling, 2003, 2007, Cutter 2006), whether it is within households (where the knowledge of women, children or the elderly may not be recognised), within communities (where divisions between social groups may hinder learning), or within nations (where indigenous groups may not be heard, and where social division and political power influence the development and adaptation agenda). In other words, these periods are frequently the times when those most affected are not consulted on their development visions and aspirations for the future. International social movements and humanitarian NGOs, government agencies and local relief organisations are all liable to impose their own values and visions, often with the best of intentions. It is also important to recognize the potential for some people or groups to prevent sustainable decisions by employing their veto power or lobbying against reforms or regulations based on short-term national or economic interests. Political vulnerability has been recognised as a key factor in shaping disaster risk (Wilches-Chaux, 1993). Fundamentally, the current spatial distribution of disaster risk is a representation of underlying processes of unequal socio-territorial development (Maskrey, 1994). Both development planning as well as post-disaster recovery have tended to prioritise strategic economic sectors and infrastructure over local livelihoods and poor communities (Maskrey, 1989 and 1996). However, this represents a missed opportunity for building local capacity and including local visions for the future in planning the transition from reconstruction into development, which can undermine long-term sustainability (ProVention report; Christoplos 2006). This is true not only for disaster risk management, but also for adaptation, and for development in general.The distribution of power in society and who has the responsibility or right to shape the future through decision-making today is significant, as discussed below.

8.2.3. Planning for the Future

Disaster risk reduction and climate change adaptation are fundamentally about planning for an uncertain future, a process that involves combining one's own aspirations (individual and collective) with perspectives on what is to come (Stevenson 2008). Typically, decision-makers (representing households, local or national governments, international institutions, etc.) look to the future partly by remembering the past (e.g., projections of the near future are often derived from recent or experiences with extreme events) and partly by projecting how the future might be different, using forecasts, scenarios, visioning processes, or story lines – either formal or informal. Although individual hazards and socio-political events can never be predicted, trends can be projected based on certain assumptions. Projections further into the future are necessarily shrouded in larger uncertainties. The most common approach for addressing these uncertainties is to develop multiple visions of the future (quantitative scenarios or narrative 'story lines') rather than a single vision, in some cases enabling the definition of alternative trajectories of change that in early years can be compared with actual directions of change.

Scenario development has become an established research tool both in the natural sciences (e.g., the SRES scenario of the IPCC) and in the social sciences (in political science, economics, military strategy and geography), based on different spatial scales (global, national and local) and temporal scales (from a few years to several decades or centuries). There is a strong tradition of predictive modeling in the environmental and economic fields, based on the quantitative and predictive orientation of dominant paradigms in the natural and social sciences, which has given rise to probablistic scenarios and forecasts of the future (Robinson, 2003). Scenario development in the social sciences is often done in several stages. As a first step, structural projections of key political determinants (population changes, urbanisation, etc.) are developed. Next, storylines reflecting different mind-sets or worldviews are designed through consultative processes, resulting in qualitative and contrasted visions of the future. Later, numerical models or expert judgements may produce quantitative and qualitative scenarios, covering socioeconomic changes, scientific and technological developments, and changes in political mindsets, worldviews and preferences. Important drivers of socio-economic changes (e.g., demography, population preferences, technologies) are highly uncertain, thus scenarios must consider a wide range of possible futures (Lempert and Collins 2007; WGBU 2008).

The challenge for disaster risk reduction and climate change adaptation is to produce regional and sub-national scenarios at longer timescales (see Gaffin et al., 2004; Theobald, 2005; van Vuuren et al., 2006; Bengtsson et al., 2006; Grübler at al., 2007; and a discussions on local scenarios in Hallegatte et al., 2008, and Van Vuuren et al., 2010; also cite the London case and some work in Paris and Phoenix, Calcutta, Mumbai, New Delhi, Lima, Dacca, Mexico City, Lagos, Cairo and Nairobi). Projections of the future are highly uncertain, because so many driving forces can change over time, especially in societies, institutions, and technologies. It is consequently difficult to base present-day decisions on future scenarios, hence choices must be made in the context of uncertainty. In particular, the situation of large uncertainty about how local climates will change makes it more difficult to analyze trade-offs and design adaptation strategies (e.g., Dessai et al., 2009a; Dessai et al., 2009b; Hall, 2007; Hallegatte, 2009; Brauch and Oswald Spring, 2009). To do so, several approaches have been proposed to deal with uncertainty. These approaches are based on robust decision-making (e.g., Groves and Lempert, 2007; Groves et al., 2007; Lempert and

Collins, 2007); or on the search for co-benefits, no regret strategies, flexibility and reversibility (e.g., Fankhauser et al., 1999; Goodess et al., 2007; Hallegatte, 2009).

With climate change, even more drastic choices may become necessary. In the many locations, for example, adapting to lower water availability may involve increased investments in water infrastructure to provide enough irrigation to maintain existing agriculture production, or a shift from current productions to less water consuming crops (see ONERC, 2009). The choices among different options depend on how the region sees itself in many decades, and on adaptation decisions that are informed by political processes. An approach that explicitly acknowledges both social and environmental uncertainties entails identification of flexible adaptation pathways for managing the future risks associated with climate change (Yohe and Leichenko, 2010). Based on principles of risk management (which emphasize the importance of diversification and risk-spreading mechanisms in order to improve social and/or private welfare in situations of profound uncertainty) this approach can be used to identify a sequence of adaptation strategies that are designed to keep society at or below acceptable levels of risk. These strategies, which policy makers, stakeholders, and experts develop and implement, are expected to evolve over time as knowledge of climate change and associated climate hazards progresses. The flexible adaptation approach also stresses the connections between adaptation and mitigation of climate change, recognizing that mitigation will be needed in order to sustain society at or below an acceptable level of risk (Yohe and Leichenko, 2010).

Visions for the future represent an important part of adaptation, as trade-offs will always be involved, and tensions inevitably arise between competing interests and visions. There is no “optimal” way of adapting to climate change or to manage risks. For instance, focusing on and acting to protect against frequent events may lead to greater vulnerability to larger and rarer extreme events (e.g., Burby, 2006), and trade-offs between short-term and long-term objectives are always involved. *Add example*. However, in discussing trade offs between addressing short term and long term risks, there will be major differences between developed country contexts, where land use is planned and regulated and developing country contexts, where most risk prone development occurs in the informal sector, and therefore by definition is not regulated. In developed country contexts, it may be possible to regulate land-use such that risks to infrequent extreme events are not increased, although political expediency will often distort the regulatory process in a way that favors the short term.

In contrast to predictive scenarios, exploratory and normative approaches can be used to develop scenarios that represent desirable alternative futures, which is particularly important in the case of sustainability, where the most likely future may not be the most desirable (Robinson, 2003). The process of “backcasting” involves developing normative scenarios that explore the feasibility and implications of achieving certain desired outcomes (Robinson 2003; Carlsson-Kanyama et al. 2008). It is concerned with how desirable futures can be attained, focusing on policy measures that would be required to reach such conditions. Participatory backcasting, which involves local stakeholders in visionary activities related to sustainable development, views the concept of sustainability not as a fixed outcome, but rather as “emergent properties of structured conversations about future options, consequences and tradeoffs, that combine expert understanding with the knowledge, values, and preferences of citizens and stakeholders” (Robinson 2003: 854).While scenarios, projections and forecasts are all useful and important inputs for planning, actual planning and decision-making is a complex socio-political process involving different stakeholders and interacting agents. In any case, developing the capacity for adaptive learning to accommodate complexity and uncertainty requires exploratory and imaginative visions for the future that support choices that are consistent with values and aspirations (Miller, 2008).

8.2.4. Technology Choices, Availability, and Access

Technologies can contribute to risk reduction and adaptation in a multitude of ways. Technology use can, of course, increase risks and add to adaptation challenges (references). For example, modern energy systems are dependent on physical structures that can be vulnerable to storm damage, as are centralized communication systems (Inderberg 2010). Lovins has suggested that relatively centralized high-technology systems are “brittle,” offering efficiencies under normal conditions but subject to cascading effects in the event of emergencies (Lovins and Lovins, 1982). More often, however, technologies are considered to be a part of the solution rather than the problem (references). One focus of this kind of perspective is on physical infrastructure, including attention to ways to “harden” built infrastructures such as bridges or buildings or natural systems such as hillsides or river channels so that they are able to withstand higher levels of stress (Larsen et al., 2007; CCSP, 2008; UNFCCC, 2006). Another focus is on technologies that assist with information collection and diffusion: e.g., technologies to monitor possible stresses and vulnerabilities, technologies to communicate with populations and responders in the event of emergencies, and technology applications to disseminate information about possible threats and contingencies. Seasonal climate forecasts based on the results from numerical climate models have been developed in recent decades to provide users with information about the coming months, which can be used to prepare for floods and droughts (Stern and Easterling, 1999).

Attention to technology alternatives and their benefits, costs, potentials, and limitations involve two different time horizons. In the near term, technologies to be considered are those that currently exist or that can be modified relatively quickly. In the longer run, it is possible to consider potentials for new technology development, given identified needs. As one example, a seacoast region facing serious concerns about surface water scarcity due to climate change might consider potentials for lower-cost desalination technologies with green energy to meet some of their needs for fresh water some decades into the future (Wilbanks, 2010). Trade-offs are also often associated with technologies and infrastructure. For example, dams could mitigate drought and generate electricity, but displace large groups of people. If dams are not constructed to accommodate future climate change, they may present new risks to society by encouraging a sense of security that ignores departures from historical experience (Wilbanks and Kates, 2010). But investments in technology infrastructures cast long shadows through time, because they tend to assume lifetimes of three of four decades or longer. If they are maladaptive rather than adaptive, the consequences for adaptability can be serious. For example, in the Mekong region, dykes, dams, drains and diversions established for flood protection often have unexpected side effects, particularly if they influence risk-taking behavior (Lebel et al. 2009).

Different countries and different social groups within countries have radically different opportunities for and constraints to choose and access technologies to address hazards, exposure and vulnerability, which is often a function of development conditions. Developed countries have been able to make major investments in physical measures to control identified hazards: the Thames barrier, which is designed to protect London against flooding, is an example of this kind of technology (Reeder et al., 2009). Due to high costs, few developing countries can afford such measures. However, regardless of costs, another issue relates to appropriateness and sustainability. While solutions based on high technology may be *implanted* in developing countries as part of bilateral and multilateral development assistance, they may not be appropriate to the surrounding social, cultural and economic context. Many such efforts fail due to apparently extra-technological reasons that are nonetheless are an integral part of the technological context. Examples include the failure of the national early warning system in Honduras during Hurricane Mitch (Villagran, 2010a), or post disaster housing projects with appropriate technology not adopted by the local population (references). This does not mean that all technologies applied in low-income countries must be home-grown and low-tech. The spread of cellular telephones in rural areas of Africa is a good example of rapid technological innovation. Nonetheless, technological innovations have to be able to insert themselves and thrive in the complexity of local societies if they are to be appropriated and sustainable.

When a disaster occurs, it has been suggested that destruction can foster a more rapid turn-over of capital, which could yield positive outcomes through the more rapid embodiment of new technologies. This effect, hereafter referred to as the “productivity effect”, has been mentioned for instance by Albala-Bertrand (1993), Stewart and Fitzgerald (2001), Okuyama (2004) and Benson and Clay (2004). Indeed, when a natural disaster damages productive capital (e.g., production plants, houses, bridges), the destroyed capital can be replaced using the most recent technologies, which have higher productivities. Capital losses can, therefore, be compensated by a higher productivity of the economy in the event aftermath, with associated welfare benefits that could compensate for the disaster direct consequences. This process, if present, could increase the pace of technical change and accelerate economic growth, and could therefore represent a positive consequence of disasters. However, this productivity effect is unlikely to be fully effective, for several reasons (Hallegatte and Dumas, 2008). First, when a disaster occurs, producers have to restore their production as soon as possible. This is especially true for small businesses, which cannot afford long production interruptions (see Kroll et al., 1991; Tierney, 1997), and in poor countries, where people have no mean of subsistence while production is interrupted. Replacing the destroyed capital by the most recent type of capital implies, in most cases, to adapt organizations and worker training, which takes time.

Producers have thus a strong incentive to replace the destroyed capital by the same capital, in order to restore production as quickly as possible, even at the price of a lower productivity. In extreme cases, reconstruction may be carried out with lower productivity, to facilitate reconstruction as fast as possible. Second, even when destruction is quite extensive, it is never complete. Some part of the capital can, in most cases, still be used, or repaired at lower costs than replacement cost. In such a situation, it may not be possible to save a part of the capital if the production system is reconstructed identical to what it was before the disaster. This technological "inheritance" acts as a major constraint to reconstruction based on the most recent technologies and needs, especially in the infrastructure sector. In addition, a larger proportion of productive assets in developed countries are fully insured, meaning that the producer at least has the opportunity to introduce new capital with increased productivity. More than 40% of direct disaster losses are insured in developed countries, compared to less than 10% in middle income countries and 5% in low income countries (Cummins and Muhul, 2009). In these latter, the inability to pay for new capital may lead to longer term decreases in productivity.

Add something here on disasters as an opportunity to integrate more appropriate technology into housing post-disaster. And a statement to acknowledge there is no research on the relationship between mitigation as a (re)design imperative and disaster safety in housing, critical infrastructure etc.

8.3. Synergies between Short-Term Coping and Long-Term Adaptation

When considering the linkages between disaster risk reduction, climate change adaptation and development, time-scales play an important role. Up until recently, disaster risk reduction efforts have fundamentally been reactive, dealing with response and reconstruction after disasters, and in the best of cases with emergency preparedness and early warning to mitigate losses when disasters happen. Progressively more attention is now being given by countries to move from an emergency management to a disaster risk reduction approach, which involves addressing exposure, vulnerability and hazards, which have different frequencies and return periods. Consequently there is now a converging focus on vulnerability reduction in the context of disaster risk management and adaptation to climate change (Sperling and Szekely, 2005). As described above, all these risk factors are dynamic and changing over time, meaning that risk levels are constantly changing. Climate change adds another level of uncertainty, raising the possibility of synergies and contradictions between actions focusing on the short-term and those required for long-term adjustment. While it is tempting to think of short-term strategies as 'coping' and long-term strategies as 'adaptation', both must be seen as processes influenced by cross-scale (spatial and temporal) interactions. This section reviews the literature regarding synergies and trade-offs. First, the implications of present day responses are assessed, particularly in relation to poverty traps. The barriers to reconciling short-term and long-term goals are then assessed. Insights from research on the resilience of social-ecological systems are then considered as a means of addressing long-term considerations. However, the limits to these approaches are then assessed within the context of thresholds and tipping points associated with rapid climate change.

8.3.1. Implications of Present-Day Responses for Future Well-Being

The implications of present-day responses to both disaster risk and climate change can be either positive or negative for human security and well-being. Positive implications can include resilience, capacity-building, broad social benefits from extensive participation in risk management/resilience planning, and the value of multi-hazard planning (references). Negative implications, which have received more research attention, include threats to sustainability if the well-being of future generations is not considered, issues related to the economic discounting of future benefits, "silo effects" of optimizing responses for one system or sector without considering interaction effects with others (see an example on the conflict between urban containment and risk management in Burby et al., 2001), equity issues regarding who benefits and who pays; and the so-called "levee effect," where the adaptive solution to a current risk management problem builds confidence that the problem has been solved for the long term, blinding populations to the possibility that conditions may change, making the present adaptation inadequate (Burby, 2006; Burby et al., 2006).

The terms coping and adaptation reflect strategies for adjustments to changing climatic (environmental) conditions. In the case of a set of policy choices, both coping and adaptation denote forms of collective conduct that aim and indeed may achieve modifications in the ways in which society relates to nature and nature to society (Elsevier 2005). Coping actions are those which take place in trying to alleviate the impacts or live with the costs of a specific event, they are usually found during the unfolding of disaster impacts – which can continue for some time after an event, for example if somebody loses their job or is traumatized. Coping strategies can help to alleviate the immediate impact of a hazard, but may also increase vulnerabilities over the medium to longer term (Sperling et al. 2008). For example, communities in the Peruvian altiplano, who are exposed to multiple hazards, tend to sell livestock to cope with the immediate impact of a climatic shock. However, this depletes the asset base of a household. In particular, because in times of climatic shocks this is wide-spread response and animals are malnourished, prices for livestock tend to be lower than usual. If a household is forced to sell its entire livestock to cope with a climatic hazard and cannot replenish these assets or diversify income sources subsequently, it will become more vulnerable to future climatic shocks as it is more dependent on climate sensitive agricultural activities (Sperling et al. 2008). In developing countries, concern for coping with the present is often fuelled by the perception that climate change is a long-term issue and other challenges, including food security, water supply, sanitation, education and health care, require more immediate attention (Klein et al 2005). Particularly, in poor rural contexts, short term coping, may be a trade-off which increases longer-term risks (ISDR, 2009, P.92). Adaptation, on the other hand, can take place before, during and after an event, but is often focused on minimizing potential risk to future losses (Oliver-Smith, 2007). Thus in post-disaster reconstruction one can find an opportunity for adaptation to building stock, while householders are still coping with damage to their livelihoods, and perhaps beginning to adapt to protect their remaining livelihood assets from vulnerability to future risk. Over the longer-term, adapting development to disaster and hazard mitigation options is based on expectations of the statistical characteristics of the hazard, and parameters such as return periods or flood frequencies.

The different time-frames for coping and adaptation can present barriers to risk management. Focusing on short-term responses and coping strategies can limit the scope for adaptation in the long-term. For example, drought can force agriculturalists to remove their children from school or delay medical treatment, which in aggregate undermines the human resource available for long-term adaptation (Norris, 2005; Santos, 2007; Alderman et al., 2006; Sperling et al. 2008). The long-term framing of adaptation can also constrain short-term coping, for example when major engineering solutions to water shortages threaten local livelihoods and undermine coping capacity. Interaction between coping and adaptation can also cross sectors, so that adaptation, if conceived for example as part of a settlement relocation scheme, can have severely detrimental impacts on short-term coping capacity and wellbeing when livelihoods and supporting social networks are disrupted. There is a large literature and much experience on this point from experience of slum relocation that is of direct relevance now to urban adaptation/coping (references).

Disasters can destroy assets and wipe out savings, and can push households into “poverty traps”, i.e. situations where productivity is reduced, making it impossible for households to rebuild their savings and assets (Zimmerman and Carter, 2003; Carter et al., 2007; Dercon and Outes, 2009; Lopez, 2009; van den Berg, 2010). The process by which subsequent events generate a vicious spiral of impact, vulnerability and risk was first recognized by Chambers (1989), who described it as the ratchet effect of disaster, risk and vulnerability. These micro-level poverty traps can also be created by health and social impacts of natural disasters: it has been shown that disasters can have long-lasting consequences on psychological health (Norris, 2005), and on child development (from reduction in schooling and diminished cognitive abilities; see for instance Santos, 2007; Alderman et al., 2006).

These poverty traps at the micro level (i.e. the household level) could lead to macro-level poverty traps, in which entire regions could be affected. Such poverty traps could be explained by the amplifying feedback reproduced in Figure 8-1. Poor regions have a limited capacity to rebuild after disasters; if they are regularly affected by disasters, they do not have enough time to rebuild between two events, and they end up into a state of permanent reconstruction, with all resources devoted to repairs instead of addition of new infrastructure and equipments; this obstacle to capital accumulation and infrastructure development lead to a permanent disaster-related under-development. This effect has been discussed by Benson and Clay (2004), and investigated by Noy (2009) and Hochrainer (2009), and modeled by Hallegatte et al. (2007) and Hallegatte and Dumas (2008) with a reduced-form economic model that shows that the average GDP impact of natural disasters can be either close to zero if reconstruction capacity is large enough, or very large if reconstruction capacity is too limited (which may be the case in less developed countries).

[INSERT FIGURE 8-1 HERE:
Figure 8-1: Amplifying feedback loop that illustrates how natural disasters could become responsible for macro-level poverty traps.]

Health, education, child development, household poverty traps and macro-level poverty traps means that short-term events can have long-lasting consequences. This can even be amplified by other long term mechanisms, such as changes in risk perception that reduces investments in the affected regions or reduced services that make qualified workers leave the regions (references). New Orleans following hurricane Betsy in 1965 provides an example of regional decline in population, even though the disaster may have been more of a trigger than the underlying cause of the decline (Colten, 2005). In conclusion, the consequences of a disaster can be much longer than what is considered the recovery and reconstruction period, and inability to cope over the short term with disaster can lead to long term consequence on development and growth.

There are many uncertainties in the ways in which people's spontaneous and organised responses to increasing climate-related hazards feed back to influence long-term adaptive capacity and options. Migration, which can be traumatic for those involved, might lead to enhanced life chances for the children of migrants, building long-term capacities and potentially also contributing to the movement of populations away from places exposed to risk (UNDP, 2009; Ahmed, 2009; Oswald Spring, 2009b; IOM, 2007, 2009, 2009a). The spectre of disappearing islands or widespread desertification that forces land abandonment will be stressful for migrants whose culture and sense of identity are affected (Montreaux and Barnett, 2008; Sánchez et al., forthcoming; Brauch and Oswald Spring, 2010). Past cases of island evacuation, for example in the case of Tristan da Cunha after a volcanic eruption in 1961, have shown the efforts to which islanders will go to preserve identity (reference). in this case isalanders preferred to return to Tristan da Cunha and face volcanic risk rather than live in an alien culture.

A broad literature on experiences of community-based and local-level disaster risk reduction, indicates options for transiting from short-term coping to longer-term adaptation, at least to existing frequently occurring risk manifestations (ISDR, 2009: 166 – 170, Lavell, 2009). Such approaches, many of which are based on community empowerment, have progressively moved from addressing disaster preparedness and capacities for emergency management, towards addressing the vulnerability of livelihoods, the decline of ecosystems, the lack of social protection, unsafe housing, the improvement of governance and other underlying risk factors (Bohle, 2009). Others aim to factor disaster risk considerations into local land-use and development planning, for example.

Addressing and *correcting* existing risk will *per se* contribute to a reduction in future risk to climate extremes. Addressing the underlying risk drivers and *anticipating* future risk will contribute to a reduction in that component of future risk to climate extremes associated with increases in exposure, vulnerability and hazard. Addressing climate change itself, through the mitigation of greenhouse gases, is a longer term process, even if international agreements on emissions are reached and implemented. Fundamentally, therefore, the process of adapting to changing climate extremes, involves addressing existing risk patterns and the underlying drivers that will shape future risk.

8.3.2. Barriers to Reconciling Short- and Long-Term Goals

Although there is convincing evidence in the literature to support disaster risk reduction as a strategy for long-term climate change adaptation, there are numerous barriers to reconciling short-term and long-term goals. Many poor countries are very vulnerable to natural hazards but cannot implement the measures that could reduce this vulnerability for financial reasons or because of a lack of technical know-how. The recent national self- assessments of progress towards achieving the HFA, indicated that some Least Developed Countries, for example, report lack the human, institutional, technical and financial capacities even to address emergency management concerns (ISDR, 2009, P.117). The development deficit in many developing country cities, where 40 – 70% of the population live in informal settlements with low levels of access to sanitation, drainage, water and health services, is an underlying driver of much urban disaster risk. Addressing this development deficit, for example investments in storm drainage, would reduce by a significant amount the consequences of many natural hazards (e.g., urban floods) in the current climate and in the future one. Doing so, however, would require very large amounts of funding (Satterthwaite et al., 2007), which are not always available. The World Bank, the UNDP and the UNFCCC estimated that the financial needs for adaptation will amount to between $9 and $166 billion per year, up to 2030. This is coherent with the MDG financing gap, which was estimated at US$73 billion in 2006 rising to US$135 billion in 2015 (Sachs, 2005). Similarly, the cost of upgrading the 800 million to 1 billion people living in informal settlements has been estimated at US$532 – 665 billion (ISDR, 2009: 184) Even though the methodologies that have been used are very questionable, the orders of magnitude are large enough to support the idea that funding will be a significant obstacle to adaptation in the future. Another obstacle is the technical know-how and access to technologies. An example is the introduction of water reuse technologies, which have been developed in a few countries, which could bring a great improvement in the management of droughts, if they could be disseminated in many developing countries (references).

Governance capacities and the inadequacy of and lack of synergy between the institutional and legislative arrangements for disaster risk reduction, climate change adaptation and poverty reduction are as much a part of the problem as the shortage of resources. In other words, money and technology are not enough to implement efficient disaster risk reduction and adaptation strategies. Differences in resources cannot explain the difference among regions (Nicholls et al., 2008). Indeed within the same country changes over time show the impact of national funding regions on the likelihood that municipal and regional authorities will shift their management of disaster risk from proactive to reactive modes. This has been noted in the US by Birkland (2007).

Differences in mortality and economic loss risk between countries is as much explained by factors such as voice and acccountabilty and institutional quality as by GDP per capita (ISDR, 2009:.26 – 44) A change in the culture of public administration towards creative partnerships between national and local government and empowered communities had been found to dramatically reduce costs (Dodman et. al., 2008). Institutional and legal environments and political will are also very important, as illustrated by the difference in risk management in various regions of the world. In many countries disaster risk management and adaptation to climate change measures are overseen by different institutional structures. This is explained by the historical evolution of both approaches. Disaster risk management originated from humanitarian assistance efforts, evolving from localized, specific response measures to preventive measures, which seek to address the broader environmental and socio-economic aspects of vulnerability that are responsible for turning a hazard into a disaster in terms of human and/or economic losses. Within countries, disaster risk management efforts are often coordinated by Civil Defense, while measures to adapt to climate change are usually developed by Environment Ministries. Responding to climate change is originally more of a top-down process, where advances in scientific research led to international policy discussions and frameworks. Adaptation is now being recognized as a necessary complementary measure to mitigation (e.g. AfDB et al. 2003). While the different institutional structures may represent an initial coordination challenge, the converging focus on vulnerability reduction represent an opportunity of managing disaster and climate risks more comprehensively within the development context (Sperling and Szekely, 2005; AfDB et al., 2003).

In addition to the barriers described above, there is also tendency for individuals to focus on the short-run and to ignore low probability events below their threshold level of concern that can have severe long-run consequences. Studies have identified a set of psychological and economic barriers as to how we make decisions under uncertainty (Kunreuther et al. forthcoming) Some of the most important elements are listed below:

Underestimation of the risk. Even when individuals are aware of the risks, they often underestimate the likelihood of the event occurring, often believing that a future disaster “cannot happen to me” (Smith and McCarty, 2006). This bias can be amplified by natural variability, which contributes to changes in event frequency over short and long periods of time (on hurricane activity and losses, see Pielke et al., 2008). It can also be exacerbated if experts disagree on the risk itself and/or the efficacy of measures to reduce its consequence. This is a particularly challenging problem in the case of estimating the future impacts of climate change and the ability of specific adaptation measures to reduce losses from floods, hurricanes and other disasters. Magat, Viscusi and Huber (1987), Camerer and Kunreuther (1989) and Hogarth and Kunreither (1995) for example, provide considerable empirical evidence that individuals do not seek out information on probabilities in making their decisions. Huber, Wider and

Huber (1997) showed that only 22 percent of subjects sought out probability information when evaluating risk managerial decisions.

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Budget constraints. If there is a high upfront cost associated with investing in adaptation measures, individuals will often focus on short-run financial goals rather than on the potential long-term benefits in the form of reduced risks. One frequently hears the following comment: "I live from pay-day to pay-day. I cannot afford the high costs of these measures" (Kunreuther et al. 1978: 113). Such a budget constraint may extend to higher income individuals if they set up separate mental accounts for different expenditures (Thaler, 1999).

Difficulties in Making Tradeoffs: Individuals are also not skilled in making tradeoffs between costs and benefits of these measures, which requires comparing the upfront costs of the measure with the expected discounted benefits in the form of loss reduction over time.

Procrastination. There is a natural tendency to postpone taking actions that require investments in time and money. The most salient is the observed tendency for individuals to defer ambiguous choices; the less certain one is about a correct course of positive action, the more likely one is to choose inaction (Tversky and Shafir 1992). Trope and Lieberman (2003) offer a wide array of evidence showing that when making choices for the distant future we tend to focus on the abstract benefits of options, whereas when making immediate choices we tend to focus on concrete costs.

Samaritan's Dilemma. People who expect public sector relief following a disaster will refuse to invest in risk-reduction measures because they feel that others (the Good Samaritans) will rescue them. Kunreuther et al. (1978) found that most homeowners in earthquake- and hurricane-prone areas did not expect to receive aid from the federal government following a disaster. Burby et al. (1991) found that local governments that received disaster relief undertook more efforts to reduce losses from future disasters than those that did not.

The Politician's Dilemma. An elected official who saddles its constituency with additional taxes for risk reduction measures that have long-term benefits may lose the next election. This NIMTOF (Not in My Term of Office) attitude often leads to inaction because the costs of undertaking protective measures are counted against one while the reduction in uncertain future losses benefits are not considered by the electorate as justifying these measures. The uninsured victims in Alaska were financially better off after the earthquake than their insured counterparts (Dacy and Kunreuther 1968). The difficulty in enforcing disaster risk reduction measures has been characterized as the *politician's dilemma* (Michel-Kerjan, 2008).

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These biases and heuristics that are exhibited by key stakeholders have led to economic development of floodplains and coastal areas subject to hurricanes, and building structures on barrier islands that are rapidly eroding. An inability to acknowledge the collective long-term consequences of individual decisions is a principal reason that societies are not well equipped to deal with climate change. Climate change is viewed as a slow-onset, multigenerational problem. Consequently, individuals and businesses are reluctant to invest in adaptation measures for reducing the impacts of climate change because they cannot justify the high upfront costs associated with these measures: there is a tendency to consider the expected benefits from adaptation over the next several years rather than over the expected life of the structure. Myopic behavior can be costly to individuals at risk and to society. There is a need to develop long-term strategies that also provide short-run returns for coping with climate change and its consequences.

Another issue that makes it difficult to reconcile short-term and long-term goals arises from the difficulty in projecting the long-term climate and corresponding risks, in order to inform risk analysis and risk management strategies. A common example is the increase in population and asset at risk from hurricanes in Florida in the last decades. Most of the population increase took place during a period (the 70's and 80's) with exceptionally low levels of hurricane losses (Pielke et al., 2008), and economic actors may have forgotten the normal level of hurricane risks in this region. This change made Florida excessively vulnerable in periods of normal activity. In the future, climate change will increase the uncertainty on climate and extreme statistics, increasing the risk of such maladaptation. For instance, in many regions climate models do not agree, even on the sign of future precipitation changes. These uncertainties make it difficult to implement optimal risk-management strategies, especially because many of such strategies require a large anticipation. For instance, building the Thames barrier to protect the London vicinity against storm surges took more than 30 years, between when construction was decided and when the barrier was fully operational: managing natural risks requires anticipating how natural hazards will change over the next decades, but uncertainty on climate change is a significant obstacle to such anticipation (Reeder et al., 2009)

8.3.3. Promoting Resilience to Connect Short- and Long-Term Goals

The previous section highlighted the importance of linking short-term and long-term goals as a means of using disaster risk reduction to advance climate change adaptation. A systems approach that emphasizes cross-scale interactions can provide important insights on how to realize synergies between disaster risk reduction and climate change adaptation. Resilience, a concept fundamentally about how *a system* can deal with disturbance and surprise, increasingly frames contemporary thinking about sustainable futures in the context of climate change. However, understandings and interpretations of resilience vary widely. It has developed as a fusion of ideas from several bodies of literature: ecosystem stability (e.g., Gunderson, 2008), engineering robust infrastructures (e.g., Tierney and Bruneau, 2007), disaster risk reduction (e.g., Cutter et al., 2008), vulnerabilities to hazards (Moser, 2008) and urban and regional development (e.g., Simmie and Martin 2010). Resilience perspectives can be used as an approach for understanding the dynamics of social ecological systems and how they respond to a range of different perturbations. In this context resilience is understood as the capacity of a system to absorb recurrent disturbances not only to retain its essential structures, processes and feedbacks but to recover to an enhanced state (Wilbanks and Kates, 2010). Originating in ecological science and closely linked to Holling's concept of the adaptive cycle (Holling, 1973; Gunderson, 2000), resilience is now used in interdisciplinary analysis of the interactions of people and nature, applied to the notion of a linked social ecological system (Berkes and Folke, 1998).

Resilience 'thinking' (Walker and Salt, 2006) may thus provide a useful framework to understand the interactions between climate change and other changes, and in reconciling and evaluating trade-offs between short-term and longer-term goals in devising response strategies. Emerging resilience theory contrasts with the conventional engineering systems emphasis on capacity to absorb external shocks. New resilience theory suggests a move "away from policies that aspire to control change in systems assumed to be stable, towards managing capacity of social-ecological systems to cope with, adapt to and shape change" (Folke, 2006, p. 254). This approach emphasizes the need to manage for change and to see change as an intrinsic part of any system, social or otherwise. For social-ecological systems (examined as a set of interactions between people and the ecosystems they depend on), resilience involves three properties: the amount of change a system can undergo and retain the same structure and functions; the degree to which it can re-organise; the degree to which the system can build capacity to learn and adapt.

The literature on resilience encompasses a range of concepts; complexity, transformability and thresholds, dynamics and disequilibria, adaptation, renewal, re-organisation and learning (e.g. Carpenter et al., 2001; Walker et al., 2004). Berkes (2007) provides a helpful summary of how resilience can inform understanding of uncertainty and vulnerability in the context of hazards. He points to three key contributions: first in providing a holistic framework to evaluate hazards in coupled human-environment systems; secondly, in putting emphasis on the ability to deal with hazard or disturbance; and thirdly, in helping to explore options to dealing with uncertainty and future changes.

Resilience thinking highlights that change and uncertainty are key features of social ecological systems; it tells us to 'expect the unexpected'. Emerging from systems ecology it is predicated on non-equilibrium – or more precisely multiple-equilibria - views of how ecosystems respond to change. The definition of resilience as the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Walker et al., 2004) itself reveals tensions between changing and staying the same – of persistence versus stability. Indeed, as Gallopin (2006) comments, when the concept of resilience is unlinked from the notion of multi-stability, it becomes very difficult to distinguish it from structural stability. According to the social ecological systems perspective however, resilience processes rely on flexibility and adaptive capacity for change rather than stability or equilibrium with return to the exact same steady state. Gundersson (2000) defines resilience as the property that mediates transition among multiple steady states or stability domains.

In ecosystems, increases in variety/novelty are associated with the greater probability of sudden transitions to new states, known as 'regime shifts' (Walker and Salt, 2006). Social-ecological systems have to deal with both gradual and abrupt changes (Folke, 2006), and in a vulnerable system, even small disturbances may initiate impressive social consequences (Adger, 2006). Innovative modeling approaches of complex adaptive social-ecological systems illustrate the tight feedbacks or integrated nature of the systems including economic and ecological dimensions. These feedbacks are generally neglected in most science and policy. Furthermore, economic models used in management of e.g. fisheries, agriculture, forestry need to be significantly changed and broadened to more realistically capture the often non-linear features of social ecological systems (Dasgupta and Mäler 2003)

Disturbances are not always bad: Folke (2006: 253) emphasizes the capacity for renewal, re-organization and development, in a resilient social ecological systems, whereby 'disturbance has the potential to create opportunity for doing new things, for innovation and for development.' The possibilities for positive change are highlighted. Resilience thinking concerns how to persist through continuous development in the face of change and how to innovate and transform into new more desirable configurations. The implication for policy is profound and requires a shift in mental models toward human-in-the environment perspectives, acceptance of the limitation of policies based on steady-state thinking and design of incentives that stimulate the emergence of adaptive governance for social-ecological resilience of landscapes and seascapes. This highlights not only adaptations to current conditions and in the short term, but 'how to achieve transformations toward more sustainable development pathways is one of the great challenges for humanity in the decades to come' (Folke, 2006: 263). Walker et al. (2004) distinguish adaptation and transformation where 'adaptability is referred to as the capacity of people in a social-ecological system to build resilience through collective action whereas transformability is the capacity of people to create a fundamentally new social-ecological system when ecological, political, social or economic conditions make the existing system untenable'. This has relevance for distinguishing between short-term and long-term responses to climate change.

Ideas about adaptive governance have recently emerged from the social ecological resilience literature. Folke (2006: 254) claims that 'the resilience perspective shifts policies from those that aspire to control change in systems assumed to be stable, to managing the capacity of social-ecological systems to cope with, adapt to, and shape change… managing for resilience enhances the likelihood of sustaining desirable pathways for development in changing environments where the future is unpredictable and surprise is likely'. Folke (2006: 262) claims that 'Adaptive governance is a major extension of conventional resource management and it consists of at least four essential parts; understanding ecosystem dynamics; developing management practices that combines different ecological knowledge system to interpret and respond to ecosystem feedback and continuously learn; building adaptive capacity to deal with uncertainty and surprise including external drivers; and supporting flexible institutions and social networks in multi-level governance systems'.

Resilience thinking is not without its critiques (references). The shortcoming often highlighted can be summarized as three dimensions: first, that in adopting a systems approach and framework to understanding the relationship between society, environment and change, it under-emphasizes the role of human agency in change and responses to change. Secondly, and following this, it depoliticizes the governance of change and the different interests, and winners and losers in different (resilience-based) strategies to address change. Thirdly, when resilience is applied in a literal sense – as it is now in widespread areas of policy globally – it tends to promote stability rather than flexibility; it can be used to maintain the *status quo* and thus to serve particular interests and not to support adaptive management, social learning or inclusive decision-making.

Resilience thinking is being applied to address disaster risk reduction and adaptation issues, and also to examine specific responses to climate change in different developed and developing country contexts. Pielke et al. (2007) have highlighted that locating adaptation policy in a narrow risk framework through concentrating only on what are identifiable anthropogenic risks, in their words, 'creates bizarre distortions in public policy' (p.597) because vulnerabilities are created through multiple stresses. Eakin and Webbe (2008) use a resilience framework to show the interplay between individual and collective adaptation can be related to wider system sustainability. Goldstein (2009) uses resilience concepts to strengthen communicative planning approaches to dealing with surprise. Nelson et al. (2007) have shown how resilience thinking can enhance analyses of adaptation to climate change. As adaptive actions affect not only the intended beneficiaries but have repercussions for other regions and times; adaptation is part of a path-dependent trajectory of change. Resilience thinking also considers a distinction between incremental adjustments and system transformation which may broaden the expanse of adaptation and also provide space for agency (Nelson et al, 2007:412). They see resilience approaches as complementary to agent-based analyses of climate change responses looking at processes of negotiation and decision-making, as they can provide insights into the systems-wide implications.

One challenge to enhancing resilience of desired system states is to identify how responses to any single stressor influence the larger, interconnected social-ecological system, including the system's ability to absorb perturbations or shocks, its ability to adapt to current and future changes, and its ability to learn and create new types or directions of change. Responses to one stressor alone may inadvertently undermine the capacity to address other stressors, both in the present and future. For example coastal towns in eastern England, experiencing worsening coastal erosion exacerbated by sea level rise, are taking their own action protect against immediate erosion in order to protect livelihoods and homes, affecting sediments and erosion rates down the coast (Milligan et al., 2009). While such actions to protect the coast are effective in the short term, in the long run, the investments to 'hold-the-line' may have diminished capital resources for other adaptations and hence reduced adaptive capacity to future sea level rise. Thus dealing with specific risks without full accounting of the nature of system resilience leads to responses that can potentially undermine long term resilience.

8.3.4. Thresholds and Tipping Points as Limits to Responses

The concept of resilience focuses on how systems respond to disturbances, including the social and ecological impacts of extreme climate events (see chapter 4). Recent literature has brought forward the possibility that climate change may lead not only to changes in the frequency and magnitude of extreme events, but also to large-scale, system-level changes, or 'tipping points' that could alter climatic and socio-economic conditions over large geographical areas (Lenton et al, 2008; Hallegatte et al., 2010). Examples of climate tipping points include dieback of the Amazon rainforest, decay of the Greenland ice sheet, and changes in the Indian summer monsoon (Lenton et al. 2008). Examples of socio-economic tipping points are profitability limits in economic activities that play a large role in a regional economy, like some crops production in agricultural regions (e.g., Schlenker and Roberts, 2006), or snow tourism in some mountainous regions (OECD report on the Alps). In the climate domain, these tipping points could significantly alter the frequency, magnitude and distribution of hydrometeorological hazards (e.g., paper by Hall on extreme sea level rise). In the socio-economic domain, they can lead to decreased resilience in the face of disasters (Hallegatte et al., 2010). Most of the scientific literature, as well as the political debate, has focused on the outcomes related to the long-term trends in climate and socio-economic variables, paying little attention to the consequences of tipping points.

Disasters are threshold-breaching events, and may provide a useful context to explore responses to tipping points. Many developing countries are already inadequately equipped to deal with current climate variability. The frequent occurrence of climate related disasters underscores this existing adaptation deficit (e.g. Burton and van Aalst, 2004). Multi-hazard environments, such as the Peruvian altiplano, may experience adverse years within the current natural climate variability, where coping capacities of communities are overwhelmed and migration of may be the only choice for some households (e.g. Sperling et al., 2008). Disasters may lead to non-local impacts, e.g., when the impacts from one disaster triggers others, as when hurricanes trigger landslides; or flooding causes the release of toxic chemicals (references) or when different hazards produce concatenated impacts over time . For example the droughts and fires during the 1997/1998 ENSO event in Central America increased landslide and flood hazard during Hurricane Mitch in 1998 (Villagrán, 2010a). Critical social thresholds may be crossed as disaster impacts spread across society. For the poor with few economic or physical assets and little protection, threats to life and health are immediately at risk; for those living in societies that take measures to protect infrastructure and economic and physical assets, the lives and health of the population are less at risk. However, this threshold can be crossed when hazards exceed anticipated limits, or are novel and unexpected, as in the 2003 European heatwave (Beniston, 2004; Schär et al., 2004; Salagnac, 2007) or when vulnerability has increased or resilience decreased due to spill-over from market and other shocks. Because climate change takes systems beyond their historical experience, tipping points may lie beyond stress levels that have ever been observed and analyzed. In some cases, possible future conditions can be simulated experimentally or observed in other places, but in many cases the only research alternative is modeling, which presents a higher level of uncertainty.

The issue of thresholds or tipping points is related to the larger issue of potentials for high consequence/low probability events to occur with climate change. In general, both the climate science community and the climate policy community have focused on very high-probability, usually relatively low-consequence incremental contingencies, rather than on possibilities for abrupt climate change or tipping points within affected systems, which are much more uncertain and difficult to analyze. Recently, however, climate science has been increasing its attention to the "fat tails" of impact probability density functions. This is in contrast to the disasters community which, after focusing on major extremes, is now recognizing the importance of small or local disasters (landslides, flashfloods or local flooding), many of which are low impact but high frequency and can have a devastating impact on those affected, with a wider erosive impact on development (UNDP, 2004; ISDR, 2009). Both lenses are valuable for a comprehensive understanding of the interaction of disaster impact with development and the ways in which capacity is eroded or built in the face of potential thresholds.

One of the challenges in considering possible impact thresholds is that they are enmeshed in multiple causation. Tipping points are seldom a function of climate change alone; in most cases, they reflect a convergence of multiple sources of stress. For instance, a forest ecosystem is more likely to see catastrophic effects from climate change if it is already under stress from regional air pollution, land use, and other driving forces. Indeed, ecologists point out that human modification and simplification of ecosystem services has reduced the capacity of ecosystems to self-regulate, thus increasing the potential for abrupt ecological changes associated with moderate climate change (Peterson 2009).

For impact thresholds, the generalization supported by the most research is that tipping points in natural and human systems are more likely to arise with relatively severe and/or rapid climate change than with moderate levels and rates (Wilbanks et al., 2007). The most direct significance of thresholds is that such non-linear change may lie beyond the capacity of adaptation to avoid serious disruptions and pain. Examples include the disappearance of Arctic sea ice, effects of climate change on traditional livelihoods of indigenous cultures in Arctic areas, widespread loss of corals in acidifying oceans, and profitability limits for important economic activities like agriculture, fisheries and tourism. When socio-economic systems are already under stress (e.g., fisheries in many countries; African agriculture), thresholds are likely to be closer and to be met earlier. Increased natural hazards, for instance, would lead to larger reduction in economic activity in places where reconstruction capacity is limited for financial or technical reasons (Hallegatte et al., 2007).

Responses to potential thresholds or tipping points range from efforts to establish monitoring systems to provide early warning of an impending system collapse, so that avoidance strategies can be considered and response strategies can be prepared, to advocacy of geo-engineering to avoid such tipping points through human interference with causes of climate change (references). Protecting all coastlines against sea level rise is probably undesirable and economically and physically unfeasible. As a consequence, choices will have to be made between human settlements that will be protected from sea level rise and human settlements that will have to be abandoned. This choice will have to be carried out through a political process, using all information that can be provided by climate scientists and sea level change projections, by coastal managers, and by socio-economic analysis. However, losses will be lower when and where abandonment is anticipated and communicated well in advance, to make it possible for all actors to manage the transition as smoothly as possible. Worst-case scenarios are those in which an area is first claimed to be protected against sea level rise and storm surges, attracting population and investments, but where protection is eventually revealed as impossible for financial, technical, or political reasons.

8.4. Interactions among Disaster Risk Management, Adaptation to Climate Change Extremes, and Mitigation of Greenhouse Gas Emissions

Responses to climate change, and climate policies, include adaptation as well as mitigation. In many instance, adaptation and mitigation will act on the same levers, such as land-use plans to reduce transport related energy-consumption and limit exposure to floods, or building norms to reduce heating energy consumption and enhance robustness to heat waves (McEvoy et al, 2006). There is an emerging literature exploring the linkages between adaptation and mitigation, and the possibilities of possible win-win strategies that address both objectives simultaneously (IPCC, 2007, Wilbanks and Sathaye, 2007; Wilbanks, 2010; Hallegatte, 2009; Yohe and Leichenko 2010). This section explores the interactions between adaptation and mitigation on the one hand, with disaster risk management on the other. Although there is not much literature on these topics together, there is a growing literature on interactions among multiple processes, which influence disaster risk reduction, climate change adaptation and mitigation of greenhouse gas emissions.

8.4.1. Adaptation, Mitigation, and Disaster Management Interactions

In an increasingly urbanised world, global sustainability in the context of a changing climate will depend on achieving sustainable cities: cities where the resilience of communities and households is greater than the risks they face. Urban spatial form is critical for energy-consumption and emission patterns, influencing where and how residents live and the modes of transport that they use, thus urban planning is a tool that can be used to pursue many goals (on the link between urban form and energy consumption due to transport, see Newman and Kenworthy 1989; Bento et al., 2005; Handy, Cao and Mokhtarian, 2005; Grazi, van den Bergh and van Ommeren, 2008; Brownstone and Golob, 2009; on the link between urban form and residential energy use, see Ewing and Rong, 2008; and on both issues, see Glaeser and Kahn, 2008). Urban form also influences urban heat islands and flood risks, thereby contributing to vulnerability to climate extremes (Desplat et al., 2009). But besides climate change aspects, urban form also influences access to jobs, leisure and amenities, and city attractiveness to professionals and businesses, with consequences for spatial and social inequalities (Leichenko and Solecki 2008; Gusdorf et al., 2008). The historical failure of urban planning in most developing country cities has had tremendous environmental and social consequences (World Bank Group, 2010; UN-HABITAT, 2009).

Mitigation actions relating to climate change are important but often less visible in rural areas, and the links to disaster management are less obvious. One common shift evident in many rural areas is the growth in wind-generation of electricity. This has the potential to reduce at least some of the power-related greenhouse gas emissions around the globe, and also represents a stable income source for many farmers. In addition, there is at least one example of recovery to a disaster involving extensive actions to ‘green’ a small community in the United States. Greensburg, Kansas, was virtually destroyed by a tornado in May, 2007. Although a disaster, the event also created an opportunity to rebuild the community from the ground up: the city has received significant attention and support in its rebuilding, and a variety of businesses and community organizations have been rebuilding to Green Building Council ‘Leadership in Energy and Environmental Design’ (LEED) Platinum standards (Harrington, 2010). Unfortunately, these actions have slowed rebuilding of the town, leading to loss in social capital while attempting to create a model ‘green’ community.

The extent to which future adaptation will be required is dependent on the extent and rapidity with which mitigation actions may be taken (references). Consequently, mitigation may be seen to be directly connected to disaster risk reduction and adaptation needs and actions.

8.4.2. Interactions among Responses

Changes in the underlying development drivers (such as urbanisation) will contribute more to future increases in risk than climate change itself (Nicholls et al., 2008; ECA Working Group. 2009). It has not been possible to estimate the contribution of climate change to increases in disaster risk, compared to other drivers of vulnerability, such as environmental degradation, the deficit in infrastructure provision (particularly drainage), and urban growth. Improved reporting of disaster loss may also be a contributing factor (reference). While a great deal of focus has been placed on the potentially catastrophic impacts of climate change outcomes such as sea-level risk on urban areas (World Bank, 2010; Nicholls et al., 2008; Hallegatte et al., 2010) probably the most immediate and generalised outcome will be a further increase in the number and impact of localised recurrent disasters in poor areas. Adaptation, therefore, has to address those underlying drivers of existing vulnerability, which are influenced by multiple, interacting stressors, and magnified by climate change.

Urbanization is a process that can compound environmental problems. More than half of the world's population was living in cities and towns (UN Habitat, 2009). Most of the growth in urban areas is in developing countries, with the world urban population in 2000 of 1.9 billion projected to more than double to nearly 4 billion by 2030 (including a growth of the urban proportion in Africa and Asia from 39% to 54-55% in this period). As countries urbanise, the risks associated with economic asset loss tend to increase (through rapid growth in infrastructure, productive and social assets, etc.) while mortality risk tends to decrease (references). As cities grow they also modify their surrounding environment, and consequently generate a significant proportion of the hazard to which they are exposed. For example, as areas of hinterland are paved over, run-off increases during storms, greatly magnifying flood hazard. As mangroves are destroyed in coastal cities, storm-surge hazard increase. Likewise, the expansion of informal settlements onto steep hillside and can lead to increased landslide hazard. Global risk models indicate that this expansion is primarily due to rapidly increasing exposure, which outpaces improvements in the capacities to reduce vulnerabilities (such as through improvements in building standards and land-use planning), at least in rapidly growing low and middle income nations (ISDR, 2009). As a consequence, risk is becoming increasingly urbanised (Leichenko and O'Brien 2008). There are dramatic differences, nonetheless, between developed and developing countries. In most developed countries (and increasingly in a number of cities in middle-income countries (e.g., Bogota, Mexico, City), risk reducing capacities exist which can manage increases in exposure. In contrast, in much of the developing world (and particularly in the poorest LDCs) such capacities are incipient at best, while exposure may be increasing rapidly. Financial and technical constraints matter for risk management, but difference in wealth cannot explain difference in risk reduction investments, which also depend on political choice and risk perceptions (e.g., Hanson et al., 2010).

Urban-planning decision-making must itself take into account multiple stresses and constraints, making it more difficult to determine an optimal approach, as trade-offs have always to be made. For instance, more parks in a city reduce urban heat island and limit heat wave vulnerability, but, if not carefully planned, they may also reduce land availability and increase rents, with negative consequence on housing accessibility by the poorest households (Oke 1987; Rosenfeld et al. 1998; Stone and Rodgers 2001; Stone 2005; Pizarro, Blakely, and Dee 2006; McEvoy, Lindley, and Handley 2006; Hamin and Gurran 2009). In addition to climate change aspects, urban planning also determines spatial and social inequalities, access to jobs, leisure and amenities, and city attractiveness to professionals and businesses (World Bank Group 2008; UN-HABITAT 2009).

Metropolitan areas depend on rural areas for provision of ecosystem services, including food production, natural resources, regulation of Earth system operations, and cultural connections with the environment. Although they provide for the needs of the world's urban majority, rural areas face considerable pressure as they cope with demographic changes, infrastructure shortcomings, rising energy prices, globalization, climate variation and change, and decisions and controls that often are external to the area. Beyond self-interest reasons for the urban majority to support improvements to disaster management and adaptation to risk and environmental change in rural areas, as well as mitigation of climate change and hazards, there are moral and ethical reasons to improve the lot of those in more isolated and potentially precarious positions might be identified.

Rural livelihoods are being transformed by a) corporatisation, globalisation, and changes in scale of farming (and other livelihood) operations; b) greater need for non-farm income in more industrial regions, where production on "family" size farms no longer generates the income needed to maintain expected living conditions without supplemental activities and income; c) increased opportunities for non-farm earnings in less industrialized regions, as previously remote areas become more integrated in national and global markets; d) shifting demands for, availability of, and controls on the exploitation of natural resources (partly due to globalisation and partly due to enhanced concerns for environmental quality); e) remittances resulting from migration (either within or across national boundaries); and f) opportunities for income from the global illicit drug industry (Chouvy and Laniel, 2007; Mansfield, n.d.). Non-farm income now represents a substantial proportion of total income for many rural households and can, in turn, increase resilience to weather and climate related shocks (Brklacich et al., 1997; Smithers and Smit, 1997; Wandel and Smit, 2000), and diversification has been used to cope with livelihood stresses and shocks or disasters (Ellis, 1998; Marschke and Berkes, 2006).

The notion of multiple stressors thus draws attention to the importance of addressing the underlying drivers of risk as a means of both disaster risk management and adaptation, and the importance of critically assessing responses so that they do not create new vulnerabilities and risks.

8.5. Implications for Access to Resources, Equity, and Sustainable Development

The previous sections of this chapter have assessed some of the ways that both disaster risk reduction and climate change adaptation influence, and are influenced by, development processes. Differences in perspectives, approaches, values, interests, and objectives (including trade-offs and tensions between short-term and long-term goals), reveal some of the challenges for building resilient and sustainable development pathways. Yet it is clear that if these challenges are not addressed, then climate-related extremes may create situations with widespread economic, social, and environmental consequences for ecosystems and humans. This section assesses some of the implications of such hazards, considered in relation to access to renewable and non-renewable resources, and to the use of environmental services for human consumption and production. Issues related to capacity and equity are discussed, including the idea that there will be winners and losers, and the implications for human security and the achievement of other international goals.

8.5.1. Capacities and Resources: Availability and Limitations

Hazards affect economic, social and cultural capital in diverse ways (Sen 2000). The capacity to manage risks and adapt to changes are unevenly distributed within and across nations, regions, communities and households (references). The literature on how these capacities contribute to disaster risk reduction and climate change adaptation emphasizes the role of economic, financial, social, cultural, institutional, and natural capital (references). Economic and financial capital can help in coping with the extreme outcomes of hazards and help to avoid disasters. Economic capital (which controls economic resources such as cash, assets) is closely linked to social capital, which is based on group memberships, relations, networks, social stratification and support that create power relations (Bourdieu and Passeron, 1977). Both capitals are interrelated with cultural capital, where forms of knowledge, skills, education and belongings have created social stratification that are reinforcing social differentiation, thus creating social vulnerability (Bourdieu, 1983). Furthermore, institutional capital (rule of law, fiscal resources, long-term planning and trained people) offers these countries the means for the prevention and mitigation of hazard impacts, and for resilience-building supported by the mass media and training in disaster risk reduction (references). Poor countries have limited economic, institutional and social assets that constrain their technological means. Within these countries, the livelihoods and wellbeing of higher social classes and castes are less affected by climate-related hazards relative to others.

Communities are seldom homogenous, and more typically consist of different social groups. These social groups are frequently stratified as the result of socio-cultural and economic factors, and thus have unequal access to resources. As a result, it is often those who have access to power and capital who have greater access to resources such as land, as compared to less endowed social groups. In some areas of the world, large parcels of arable land are owned by wealthy individuals who are often absentee land owners, blocking access to such land, water, and other resources needed by smallholder farmers (Ifejika Speranza, 2006). Poor people throughout the world are therefore severely affected when their access to resources is restricted. This is attributed to the fact that poor people generally depend more on ecosystem services and products for their livelihoods than wealthy people. The means by which a poor family gains an income and meets its basic needs are often met by multiple livelihood activities. For example, exploiting common property resources such as fish, grazing land or forests can provide income, food, medicine, tools, fuel, fodder, construction materials and so on. As a result of this dependency, any impact that climate change and natural disasters have on natural systems threatens the livelihoods, food intake and health of poor people (Smith & Troni, 2004; Reid, 2004).

Some demographic groups, such as children, stand out as more vulnerable to climate change-related extreme events. The vulnerability of children and their capacity to respond to climate change and disasters is discussed in Box 8-1. Importantly, an increasing number of elderly will also be exposed to climate change in the coming decades, particularly in OECD countries. By 2050, it is estimated that 1 in 3 people will be above 60 years in OECD countries, as well as 1 in 5 at the global scale (United Nations, 2002). The factors that contribute to the vulnerability of people over 60 years of age to climate change are similar to factors that make them vulnerable to other types of hazards: deterioration of health, personal lifestyles, loneliness, poverty, or inadequate health and social structures are all elements that can contribute to vulnerability (OECD, 2006). The context in which people are aging will also influence future vulnerability to climate change. This context includes changing health conditions, as well as issues of social exclusion; welfare programme reforms and their impact on the elderly income; developments in the health and social care system; and finally, the evolution of family structures (references).

_____ START BOX 8-1 HERE _____

Box 8-1. Children, Extremes and Equity in a Changing Climate

Building sustainable and resilient societies in the future will require the inclusion of future generations in decision making, both as future inheritors of risks and as actors in their own right. The linkages between children and extreme events have been addressed through two principle lenses:

1. Differentiated Impacts and Vulnerability

Children's relative vulnerability to extreme events has been a key feature of the literature, with estimates that 66.5 million children affected annually by disasters (Penrose and Takaki, 2006). Research on post-disaster vulnerabilities focuses on psychosocial impacts on children and the short and long term physical health implications of disaster (Bunyavanich et al, 2003; Balaban, 2006; Bartlett 2008; del Ninno and Lindberg, 2005; Norris et al. 2002; Waterson, 2006). This characterises their vulnerability in part due to their less developed physical and mental state and therefore differential capacities to cope with deprivation and stress in times of disaster (Bartlett 2008; Cutter 1995, Peek 2008).

Most literature points towards higher mortality and morbidity rates among children for climate stresses and extreme events (Bartlett 2008; Sanchez et al 2009; Telford et al, 2006; Cutter, 1995; Waterson, 2006; McMicheal et al, 2008; Costello et al, 2009). This is especially acute in developing countries, where climate-sensitive health outcomes such as malnutrition, diarrhoea and malaria are already common and coping capacities are lowest (Haines et al, 2006), although research in the USA found relatively low child mortality from disasters and considerable differences across age groups for different types of hazard (Zahran et al, 2008).

These studies underpin the need for resources for child protection during and after disaster events (Last 1994; Jabry 2002; Bartlett 2008; Lauten and Lietz, 2008; Weissbecker et al, 2008). These include protection from abuse and schooling, especially during displacement, social safety nets to guard against withdrawal from school due to domestic or livelihood duties, and dealing with psychological and physical health issues (Norris et al, 2002; Evans and Oehler-Stinnett, 2006; Bartlett 2008; Lauten and Lietz, 2008; Keenan et al 2004; Peek 2008; Waterson, 2006; Davies et al, 2008).

2. Children's Agency and Resource Access

There is increasing acknowledgement that rather than just vulnerable victims requiring protection, children also have a critical role to play in tackling extreme events in the context of climate change (Tanner, 2010). Children and youth movements have grown globally in campaigning for climate change mitigation actions in their own communities. They have also been increasingly active on the global policy stage, culminating in formal recognition of the Youth NGO Constituency (YOUNGO) within the UNFCCC process in 2009, giving young people a formal voice at the negotiating table (UNJFICYCC, 2009). There is also increasing attention to child-centred approaches to preventing, preparing for, coping with, and adapting to climate change and extreme events (Peek, 2008; Tanner, 2010).

While often centred on disaster preparedness and climate change programmes in education and schools (Wisner, 2006; Bangay and Blum, 2010), more recent work emphasises the latent capacity of children to participate directly in DRR or adaptation supported through child-centred programmes. This emphasis acknowledges the unique risk perceptions and risk communication processes of children, and their capacity to act as agents of change before, during *and* after disaster events (see collections of case studies in Peek, 2008; in Back *et al,* 2009; and in Tanner, 2010). Examples demonstrate the ability to reduce risk behaviour at households and community scale, but also to mobilise adults and external policy actors to change wider determinants of risk and vulnerability (Tanner et al 2009; Mitchell et al, 2008). The implication of these studies is that greater resources should be channelled towards children's agency, including enhanced efforts to incorporate children's perspectives, knowledge, and potential for action into regular community-driven development programmes (Tanner et al, 2009).

_____ END BOX 8-1 HERE _____

Traditional knowledge and cultural and biological diversity may reduce the risks of future hazard impacts, but their role is often ignored in preventive disaster risk management, and in reconstruction processes (references). In contrast, the role of culture, including traditional knowledge, has been increasingly recognized in the climate change literature (Heyd and Brooks 2009). For example, the small size of plots that smallholder farmers own is exacerbated by cultural practices, whereby land is sub-divided among the younger generation based on the traditional notion of providing land resources to sons to enable them to farm. This tradition further reduces land available for agriculture and the units that individual farmers can access. Under conditions of low input and manual agriculture, the small plots are just big enough for the farmers to be able to work them manually. But also dominance of patriarchal systems of land inheritance that hinders access to land by women, who constitute the larger proportion of African agricultural labour (Verma, 2001; Eriksen et al., 2005; Ifejika Speranza, 2006a).

Studies also show that poor households, particularly female-headed households, are more likely to borrow food and cash than rich and male headed households during difficult times. This coping strategy is considered to be a dangerous one as the households concerned will have to return the food or cash soon after harvests, leaving them more vulnerable as they have less food or cash to last them the season and to be prepared if disaster strikes (Young and Jaspars 1995). This may leave households in a cycle of poverty from one season to the next. Literature shows that this finding has to do with unequal access to resources by females in many countries. Females have been found to have less access to resources such as land, property and public services (Agarwal, 1991; Nemarundwe, 2003; Njuki et al., 2008; Thomas-Slayter et al., 1995).

8.5.2. Sustainability of Ecosystem Services in the Context of DRR and CCA

Ecosystems can act as natural barriers against climate-related extremes. However, their presence alone cannot be used as a disaster reduction strategy. Ecosystem health, resilience and level of intervention can affect how a natural system responds to the forces of nature, and hence be considered part of disaster risk reduction strategies. The event itself, the geomorphology of the area, and the geography and location of the system in respect to the source of the event are also crucial factors influencing how each ecosystem can respond to the forces of nature (Lacambra *et al* 2010). In assessing the ecological limits of adaptation to climate change, Peterson (2009) emphasizes that ecosystem regime shifts can occur as the result of extreme climate shocks, but that such shifts depend upon the resilience of the ecosystem, and is likely to be influenced by processes operating at multiple scales. There is evidence that the likelihood of regime shifts may increase when, among other changes, the magnitude, frequency, and duration of disturbance regimes is altered (Folke et al. 2004).

The use of ecosystem approaches to adaptation include the conservation of water resources, wetlands for both hydrological sustainability and human water supply; forest conservation for carbon sink and alternative source of energy such as the use of biofuels to reduce carbon emission (IIED 2006); coastal defences; and avalanche protection (Silvestri and Kershaw, 2010). Any change in the constituents of an ecosystem can change the ecosystems dynamics and interact with other systems, altering their resilience as described by Holling (1973), leading sometimes to unexpected results (Gordon et al. 2008; Peterson 2009), including the elimination of the ecosystem and the services they provide.

Biodiversity can also make important contributions to both disaster risk reduction and climate change adaptation. Functionally diverse systems may be better able to adapt to climate change and climate variability than functionally impoverished systems (Lacambra et al, 2010, Elmqvist *et al.,* 2003; Hughes et al, 2003). A larger gene pool will facilitate the emergence of genotypes that are better adapted to changed climatic conditions. As biodiversity is lost, options for change are diminished and human society becomes more vulnerable (IIED 2004). For example, at a watershed level, forests on higher lands prevent soil erosion and flashfloods in lower areas (Oswald Spring et al., 2010). Mangrove forests, for example, are a highly effective natural flood control mechanism which will become increasingly important with sea level rise, and are already used as a coastal defence against extreme climatic and non-climatic events, mostly in Asia (Adger et al., 2009). Conservation of biodiversity and maintenance of ecosystem integrity may be a key objective towards improving the adaptive capacity of such groups to cope with climate change; both have been directly related to ecosystem resilience, which in turn is related to the capacity of ecosystems to respond to disturbances (Peterson *et al.*, 1997; Elmqvist *et al.,* 2003).

In some cases, strategies that are adopted to reduce climate change through greenhouse gas mitigation can affect biodiversity, both positively and negatively, which in turn influences the capacity to adapt to climate extremes. For example, some bio-energy plantations replace sites with high biodiversity, introduce alien species and use damaging agrochemicals which in turn reduce ecosystem resilience and hence their capacity to respond to extreme events. Large hydropower schemes can cause loss of terrestrial and aquatic biodiversity, inhibit fish migration and lead to mercury contamination (Montgomery et al 2000), as well as change watershed sediment dynamics, leading to coastal areas sediment starvation which in turn could lead to coastal erosion and make coasts more vulnerable to sea level rise and storm surges (Silvestri and Kershaw, 2010).

Ecosystem-based approaches to adaptive management can reduce disaster risk and contribute to climate change adaptation (references). For example, integrated watershed management can conserve watershed biodiversity in addition to increasing water retention and availability in times of drought; decreasing the chance of flash floods and maintaining vegetation as a carbon sink (Silvestri and Kershaw, 2010). Reducing deforestation maintains and protects biodiversity, soils, water, and many other ecosystem services that are normally not taken into account such as pollination, local climate regulation, biomass production among others, but may result in a short-term loss of economic welfare for some stakeholders, which contributes to vulnerability. Although ecosystem-based approaches can contribute to climate change adaptation; such strategies require research and understanding of local level ecological and social processes, including ecosystem dynamics and the interactions with human communities (Walker and Salt, 2006). The thresholds at which ecosystems can both act as barriers against climate-originated disturbances and adapt to climate change remain still unknown (references).

8.5.3. Local, National, and International Winners and Losers

While climate-related hazards cannot always be prevented, the number of victims (deaths, affected people) and the economic damages have differed significantly in the past due to different degrees of social vulnerability. In many hazard-affected countries, the degree of social vulnerability is influenced by multiple discriminations based on class, caste, race, ethnicity, religion, gender and age (Aryabandu and Fonseka 2009; Oswald Spring, 2008). Disasters often draw attention to the losers – those whose lives, livelihoods, and/or system viability are adversely affected by climate-related extremes. However, there are also winners associated (at least indirectly) with disasters, including suppliers of materials, equipment, and services during an emergency response period and during the reconstruction (West and Lenze, 1994; Hallegatte, 2008), or other areas or systems that gain competitive advantage (e.g., areas that appear more attractive as investment targets or tourism destinations because they are considered less vulnerable).

Analyses of winners and losers of climate-related hazard impacts requires a distinction between the analysis of the “final state”, which can be considered more desirable than the initial situation (e.g., a warming in cold world regions), and the analysis of the transition toward that final state. Sometimes, the fact that the final state is viewed as more desirable than the initial one does not imply that the transition between the two states will not be difficult, for instance because it requires high investments and economic reconversion (Hallegatte et al., 2010).

Analyses of winners and losers of climate-related hazard impacts require a distinction between linear projections of global climate change and non-linear thresholds that may trigger tipping points of ecological and social systems. While some countries may experience initial benefits from an increase in temperature and precipitation (e.g. in

Canada, Northern Europe, Russia), they may also be negatively affected by sea level rise and the projected increase in the number and intensity of hazards. However, some of these same countries may be losers of an abrupt climate change due to changes in the Gulf Stream – one of several possible tipping points that may exist (Lenton et al., 2008). Whether or not a particular place/area is a winner or loser from an extreme event or a combination of climate extremes and other driving forces also depends on external (and internal) perceptions that are shaped by the recovery process, as well as by subjective factors such as values (O'Brien, 2009; O'Brien and Wolf, 2010).

Places that respond by using a renewal process to make themselves better can convert losses to wins, which is one aim of community resilience (references). Moreover while climate change associated trends in warming or precipitation may yield benefits, extremes embedded within these trends may be less positive making planning for climate change more problematic. Further uncertainty for possible winners comes from balancing any benefits from direct local impacts with exposure to indirect global consequences of climate change (which could be beneficial or detrimental to local business and costs of living), through for example volatility in global food or other resource markets.

Every risk management strategy is associated with winners and losers at every scale, from local to international. In most cases, the contrasts are most dramatic at relatively local scales where the impacts, real or potential, are much more salient and the choices represent a larger share of a local economy, ecology, or society (references). Climate variability has been documented to cause costly impacts for OECD countries that have a relatively high coping capacity, as the impacts of the heatwave in Europe, of Hurricane Katrina in the United States and the repeated forest fires in South Europe, the United States and in Australia have in recent years demonstrated (references). Lurking behind discourses about winners and losers is the issue of liability for losses: i.e., if a population or an area experience severe losses due to an extreme event (at least partly) attributed to climate change, whose fault is it? At some point during the next half-century, it seems likely that this kind of effort to assign blame will emerge as an issue for both governments and courts. Issues of equity, justice, and compensation are thus increasingly being raised (O'Brien et al., 2010).

8.5.4. Potential Implications for Human Security

Changes in climate-related extreme events threaten human security, and both disaster risk reduction and climate change adaptation represent strategies for both improving human security and avoiding disasters. Human security can be understood as freedom from fear, freedom from want, freedom to live in dignity, and freedom from hazard impacts (UNDP, 1994; Sen, 2003; Annan, 2005; Bogardi and Brauch, 2005; Brauch 2005, 2005a). Human security can also be thought of as the capacity of individuals and communities to respond to threats to their environmental, social, and human rights (GECHS, 1999; Barnett et al., 2010). Human security addresses the combined but related challenges of upholding human rights, meeting basic human needs, reducing social and environmental vulnerability (UNDP, 1994; Brauch, 2009a; Fuentes and Brauch 2009).

The physical effects of climate change (e.g., temperature increases, sea level rise, precipitation changes and extreme weather events) will have multiple societal consequences which under certain conditions pose dangers to human security. Among the most likely human security threats are impacts on health, food, water and soil (Oswald Spring, 2009a; Oswald Spring et al., 2010). A number of studies have assessed the relationship between climate change and security, demonstrating that the linkages are often both complex and context-dependent (Barnett 2003, Barnett and Adger, 2007; Buhaug et al., 2008; O'Brien et al., 2010). For example, negative impacts of climate change on food security over the medium- and long-term are likely to create greater emergency food aid needs in the future (Cohen, 2007). Among the most widely-discussed humanitarian and human security issues surrounding climate change are the possibilities of mass migration and/or violent conflict as the result of biophysical or ecological disruptions associated with climate change. Migration and conflict are emerging as key security concerns among national governments and international institutions, are both issues are intricately related to the existing vulnerability context that disaster risk reduction and climate change adaptation are targeting.

In the poorest rural areas, many people are only just coping and surviving even in normal years due an absence of assets and reserves, and human development conditions characterised by high levels of malnutrition, high rates of infant mortality, lack of high levels of education and insufficient medical care. Approximately 75% of the people living below the World Bank defined international poverty line of US$1.25 dollars per day live and work in rural areas (with 268 million in sub-Saharan Africa, 223 million in East Asia and the Pacific and 394 million in East Asia alone) (World Bank, 2009). When affected by a hazard impact, or simply ongoing stress, coping often fails. This may lead to sometimes dramatic declines in human development indicators (possibly low at the outset) and, in extreme cases, large scale migration and increased mortality (Sánchez et al., forthcoming). There are indications that such conditions followed stresses in the distant past, as well as in current situations (see, e.g., Kinzig et al., 2006; Le Roy Ladurie, 1971; Peeples, Barton and Schmich, 2006). Yet, when affected by a hazard impact, coping often fails, leading to a sometimes dramatic decline in already low human development indicators and in extreme cases large scale migration or even mortality. For example, Rodriguez-Oreggia et al. (2009) focus municipalities in Mexico that are affected by disasters see an increase in poverty by 1.5 to 3.6 percentage point.

Migration is a key coping mechanism for poor rural households, not only in extreme circumstance, for example, during a prolonged drought, as with the 20th Century U.S. Dustbowl period and Sahelian droughts (Scheffran, 2010) but also as a means of diversifying and increasing income. Disasters linked to extreme events often lead to displaced people, refugees, relocated communities and temporary or permanent migration. The relationship between climate risk and displacement is a complex one and there are numerous factors that affect migration. Nonetheless, recent research suggest that adverse environmental impacts associated with climate change have the potential to trigger displacement of an increased number of people (Kolmannskog, 2008). Studies further suggest that most migration will take place internally within individual countries; that in most cases when hydro-climatic disasters occur in developing countries they will not lead to net out-migration because people tend to return to re-establish their lives after a disaster; and that long term environmental changes are likely to cause more permanent migration (Piguet, 2008;UNEP, 2009). Worldwide remittance flows are estimated to have exceeded US$318 billion in 2007 of which developing countries received US$240 billion (World Bank, 2008). On the negative side, migration to cities and urbanisation may lead to the breakdown of traditional rural households and coping mechanisms; rapid increases in the number of female headed households as men migrate (Oswald Spring, 1991, 2009); the ways in which towns and cities often displace their environmental burdens and risks to rural hinterlands, etc. (García, 2004).

During times of stress, it is easy for polities to drift towards militarization which promises clear leadership, and authoritarianism can offer limited success in managing disaster risk (Albala-Bertrand, 1993). Institutions in society that are responsible for national and international security are beginning to discover climate change as a potential threat. For example, the first federal government agency in Germany to publicly recognize climate change as a threat to national well-being was the Federal Ministry on the Environment, Nature Conservation and Nuclear Safety (BMU, 2002). The UN Security Council first debated climate change on 17 April 2007. Later the UN General Assembly adopted a Resolution on Climate Change and International Security on 11th June 2009 (A/RES/63/281), requesting the UN Secretary General to submit a Report, which was released on 11th September 2009 (UN/SG, 2009). Concerns range from possible needs for humanitarian assistance to possible causes of environmental migration, emergent disease for humans or in food chains, potentials for conflict between nations or localities over increasingly scarce resources, and potentials for political/governmental destabilization due to climate-related stresses in combination with other stresses, along with efforts to assign blame (Brauch and Oswald Spring, 2010).

Disaster response is often better at meeting basic needs than securing or extending human rights. Indeed, the political neutrality that underpins the humanitarian imperative makes any overt actions to promote human rights by humanitarian actors difficult. In this way disaster response and reconstruction can to only a limited extent claim to enhance human security (Pelling and Dill, 2009). Work at the boundaries between humanitarian and development actors, new partnerships, the involvement of government and meaningful local participation are all emerging as ways to resolve this challenge. One successful case has been the reconstruction process in Aceh, Indonesia following the India Ocean Tsunami, where collaboration between government and local political interests, facilitated by international humanitarian actions on the ground and through political level peace building efforts have increased political rights locally, contained armed conflict and provided an economic recovery plan (Gaillard et al, 2008).

Coping with the new and unprecedented threats to human societies posed by climate change has raised questions about whether existing geopolitics and geostrategies have become obsolete (Dalby, 2009). The concepts, strategies, policies and measures of the geopolitical and strategic toolkits of the past as well as the short-term interests dominating responses to climate change have been increasingly questioned, while the potential for unprecedented disasters has led to a consideration of the security implications of climate change (UNSC, 2007; EU 2008, 2008a; SIDS 2009, UNGA 2009; UNSG 2009). Adaptation planning that seeks long-term stability is continually confronted by political vulnerability directly after disasters (Drury and Olson, 1998; Olson, 2000; Pelling and Dill, 2009, UNDP, 2004) . When disasters strike across national boundaries or within areas of conflict, they can also provide a space for rapprochement, but effects are usually short lived unless the underlying political and social conditions are addressed (Kelman, 2003; Kelman and Koukis, 2000).

The growing interest of the security policy and research communities in climate change vulnerability and security issues is having a powerful effect on climate science, which has historically concerned itself almost entirely with high-probability climate futures. The security communities, by contrast, are responsible for contingency planning for relatively low-probability/high-consequence possible futures, and they are bringing this perspective into climate science. Examples of benefits from this new fusion of interests include the *valuation* of low-probability/high consequence contingencies as an issue related to *budget allocations* for addressing such contingencies (references). It also draws attention to alternatives that can promote human security. Inclusive governance, for example, is an alternative that can meet the goals of sustainable development and human security over the long-term (Brauch, 2009a; Bauer, 2010, Olson and Gawronski, 2003; Pelling and Dill, 2003).

8.5.5. Implications for Achieving Relevant International Goals

Addressing – or failing to address -- disaster risk reduction and climate change adaptation can influence other international goals. Numerous potential international goals can be discussed, including 1) the Millennium Development Goals; 2) the Habitat Agenda Goals and Principles; and 3) international environmental agreements (Convention on Biodiversity). It is also important to to consider how the integration of disaster risk reduction considerations into development assistance frameworks (such as Common Country Assessments, United Nations Development Assistance Frameworks and poverty reduction strategies, together with the protection and recovery of ecosystems) can influence climate change adaptation (ISDR, Hyogo Framework for Action 2005-2015).

The shift towards a more preventive approach, that focused on reducing vulnerabilities to disasters, was already evident when the UN General Assembly declared 1990 to 1999 the International Decade for Natural Disaster Reduction (IDNDR). An outcome of this was that the World Conference on Natural Disaster Reduction in Yokohama, 1994, conceived the Yokohama Strategy and Plan of Action for a Safer World, which stressed the responsibility of countries to protect its people and assets from the impact of natural disasters. While this represented a shift from a mainly reactive approach towards a more comprehensive approach (Sperling and Szekely, 2005), it was only at the World Conference on Disaster Risk Reduction (WCDR) in Kobe, 2005, that climate change was explicitly recognized as an integral concern for disaster risk management. The *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters* (HFA) recognizes the climate variability and change as important contributors to patterns of disaster risk and includes strong support for better linking disaster management and climate change adaptation efforts (Sperling and Szekely, 2005).

There is a debate on whether disasters are currently a problem *of* development, or a problem *for* development; in other words, the relationship between disasters and economic growth and development is not clear (references). Regardless of the current debate, climate change is likely to influence the conclusion, showing that both perspectives are valid. Disaster response is related to development issues, especially at local level, where authorities are often not prepared for preventive behavior. Further more hydro-meteorological events occur in developing countries. All disasters have an effect on the GDP of the affected regions and therefore countries in the South are higher threatened by. There are direct impacts from disasters and indirect ones, which are often bigger and remain for longer time. For example, hurricanes and landslides destroy transportation and communication systems and tourist infrastructure avoiding activities after the disaster, sometimes for several months or yearsw. These indirect damages could be bigger than the direct ones, increasing economic crisis and unemployment (see Wilma, Mitch, etc.).

Arguments for addressing disaster risk and climate change not only through targeted risk management but as a core aspect of development planning draw on a range of arguments. The Risk Society thesis by Ulrick Beck (1992) and linked discussion on late-modernity by Antony Giddens (2009) amongst others both champion enhanced communication between science and policy and more inclusive governance for the linkages between development and risk to be more clearly understood and acted upon. In civil society disquiet about the excesses of consumption have fed into global environmental and climate change movements. In the development community and private sector the quality rather than quantity of exchange relations is coming under increased scrutiny. Many critiques seek to frame climate change responses not as a loss of value or utility, but as a way of enriching life while also reducing risk (references).

More tangible examples of emerging visions for encouraging climate change adaptation and disaster risk reduction are still limited. Potential players include the global private sector (for instance, the World Business Council for Sustainable Development), major non-governmental organizations (for instance, the International Federation of Red Cross and Red Crescent Societies). Examples of subjects under discussion include relating the next set of Millennium Development Goals to climate change adaptation and risk management.

8.6. Options for Proactive, Long-Term Resilience to Future Climate Extremes

Building a sustainable and resilient future will require an integrated and ambitious policy response that is science-based and knowledge-driven, and that is capable of addressing issues of heterogeneity and scale. The latter issues are particularly vexing, as the actual impacts of climate change and disasters are local, and most aspects of resilience need local action and institutions but very often the responses also need to be implemented through actions at regional, national and global scales. Policy approaches that can resolve conflicts and exploit synergies between multiple objectives related to sustainable development, disaster risk reduction and climate change adaptation are likely to be most effective. This section therefore first reviews the literature pertaining to policy options, then considers actions and responses for achieving multiple objectives, which typically include trade-offs in decision-making. The importance of learning, innovation, transitions, and transformations are then considered in relation to disaster risk reduction and climate change adaptation. Finally, the role of actors and agency are discussed.

8.6.1. Review/Assessment of Bridging Practices, Tools, and Approaches

There are a number of potential practices, tools and approaches for addressing disaster risk, climate change adaptation and poverty reduction. Policy frameworks provide the basis for responding to extreme events. As discussed in Chapter 7, the Hyogo Framework for Action (HFA) was adopted by 168 countries in 2005, and provides a technical and political agreement on the areas that needs to be addressed to reduce disaster risk. The HFA presents five priorities for action: 1) ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation; 2) identify, assess and monitor disaster risks and enhance early warning; 3) use knowledge, innovation and education to build a culture of safety and resilience at all levels; 4) reduce the underlying risk factors; and 5) strengthen disaster preparedness for effective response at all levels.

Practices, tools, and approaches for improving risk management related to climate extremes are related to such needs as information-gathering and monitoring, information analysis and assessment, projections of possible futures, and exercises to simulate threats and explore implications of responses. For example, one need is to combine understandings of potential stresses from climate extremes, along with possible tipping points for affected systems, with monitoring systems for tracking changes and identifying emerging threats in time for adaptive responses, where possible. Another need is for approaches to analysis and assessment that include both quantitative analysis and qualitative integrative deliberation (references). Possible futures need to be projected and discussed with the help of scenarios and narrative story lines (Tschakert and Dietrich, 2010). In many cases, it is also very helpful to use simulations of possible extremes and associated disruptive impacts to engage stakeholders and responders in situations that help them understand both threats and effective responses (Nichols et al., 2007).

Progress is being made to improve the availability of risk information to decision makers. This includes efforts to create national institutions to manage risk information (Von Hesse, Kamiche and de la Torre, 2008) which bring together previously fragmented efforts centred in national meteorological, geological, oceanographic and other agencies. New open source tools for comprehensive probabilistic risk assessment (GFDRR, nd) are also beginning to offer ways of compiling information at different scales and from different institutions to generate a vision of risk that can allow decisions to be made. A growing number of countries are also systematically recording disaster loss and impacts at the local level, enabling estimations of the extent, cost and frequency of climate related disaster events (DesInventar, 2010).

Other countries are developing mechanisms to use such information to inform and guide public investment decisions (Comunidad Andina and GTZ, 2006; Comunidad Andina, 2009; Von Hesse and Kamiche and de la Torre, 2008) and for national planning. Major investments in infrastructure (including ports, airports, transportation systems, energy generation and water supply systems, irrigation systems, etc.) typically have a planned life of 50 – 150 years and provide a spatial structure for other public and private investments in business, housing, social and local infrastructure. In other words, such investments will have a critical bearing on long-term risk patterns in the future. Ensuring that such investments take into account likely patterns of future climate hazard is therefore key to a sustainable future.

While it is impossible to *correct* major concentrations of existing risk, through retrofitting or relocation, national public investment systems informed by comprehensive risk assessments can be a means to *anticipate* future risk by guiding new investment to areas with lower hazard levels, particularly taking into account climate change outcomes such as sea-level rise, declining freshwater availability and increased flooding and drought. Opportunities also arise when existing or obsolete infrastructure is replaced or upgraded or when it is rebuilt following damage or destruction in a disaster. Clearly, as described early in this chapter, this raises trade-offs between a long-term reduction in losses and short term economic gains (Satterthwaite et. al, 2009b).

Urban planning is one of the adaptation strategies that can reduce disaster risk, but it takes time to produce significant effects. Using urban planning to adapt to climate change requires an unprecedented anticipation of future climate change, taking into account how climate will change over many decades and the uncertainty on this information. This requires moving from short-term perspectives (25 or 30 years) to up to 100-yr perspectives. This change implies new challenges, and new methodologies will have to be developed. For instance, climate change risk analysis requires local urban scenarios, which are particularly difficult to design as they depend on innumerable parameters (see Section 8.2.3). Urban forms imply strong inertia and irreversibility: when a low-density city is created, transforming it into a high density city is a long, expensive, and difficult process. This point is crucial in the world's most rapidly-growing cities, where urban forms of the future are being decided based on actions taken in the present, and where current trends indicate that low-density, automobile dependent forms of suburban settlement are rapidly expanding (Solecki and Leichenko, 2006). Recent work has started to investigate these aspects (Newman 1996).

At the same time, there are specific opportunities when cities enter periods of large scale transformation. This is happening in Delhi, Mumbai and other cities in India as private capital redevelops low-income city neighbourhoods into commercial districts and middle- and high-income housing areas. There is rare scope here to build disaster risk reduction and climate change adaptation and mitigation alongside existing demands for social justice into urban and building design. These are extreme examples of low-income settlement transformation that is occurring worldwide through processes of gentrification or large-scale renewal. While vulnerability is not resolved through such transfers of land from the poor to middle and high-income land use there is potential for building mitigation into urban design through integrated land-use planning and climate smart building design. There are also a growing number of large-scale 'slum' /informal settlement upgrading programmes that are improving housing and living conditions for low-income households (Boonyabancha 2005, Satterthwaite 2010). These improving housing conditions and install or upgrade infrastructure and services – and as such reduce disaster risk. These also have the potential to build greater resilience to many likely impacts of climate change.

Other innovative experiences are also emerging in the area of land-use planning and urban governance, which can also play a key role in *anticipating* future risk and hence address one of the key underlying risk drivers outlined above. Conventional approaches to land-use planning have generally failed to provide land for low-income urban dwellers, with a consequence, already mentioned above that over 1 billion urban dwellers live in informal settlements, often in hazard prone locations and with a number increasing by 25 million per year. Again, as mentioned above, planning and building regulations and standards are often an obstacle to providing safe land for the urban poor, given that inappropriate standards, waiting lists, cut-off dates and other mechanisms are used to exclude poor households. However, processes where organizations representing low-income urban households have been able to negotiate with urban governments, have shown that it is possible to identify and finance land-acquisition for the urban poor in safer locations, as well as support the development of housing and infrastructure (ISDR, 2009, 154 – 156; Satterthwaite, 2009a).

The most successful programmes are those that – while community- or locally based – have developed broader partnerships with governments and other supra-local stakeholders (see Box 8-2). Many of the underlying risk drivers cannot be addressed by community organizations on their own and some are also beyond the capacities of local governments. Partnerships with national agencies permit scaling-up of initiatives to go beyond individual communities and localities to address problems that affect wider areas, such as watersheds and coastlines. They enable the investment of resources that are unavailable locally and increase continuity and sustainability as initiatives move from stand-alone projects and programmes to longer-term processes. Many of these more successful initiatives would appear to have been catalysed by decentralisation processes, in which more competent and better resourced local governments are able to play a more active role in addressing disaster risk. Most of the cases where sustainable local processes have emerged are where national governments have decentralized both responsibilities and resources to the local level, and where local governments have become more accountable to their citizens as for example in cities in Colombia such as Manizales (Velásquez, 1998; Velásquez, 2005). In Bangladesh and Cuba success in disaster preparedness and response, leading to a real and drastic reduction in mortality due to tropical cyclones, builds on solid local organization, but in both cases it has received sustained support from the national level (references).

_____ START BOX 8-2 HERE _____

Box 8-2. Strengthening Local Capacities Reduces Catastrophic Disaster Risk

In the municipality of La Masica, Honduras, a local level early warning system was developed in 1997, with support from the Organisation of American States (OAS), GTZ and the Network for Social Studies on Disaster Prevention in Latin America (LA RED) to assist the population to reduce their risks to local flooding in a small-river basin. When a catastrophic hazard event occurred in 1998 (Hurricane Mitch) the municipality was as exposed as others on the north coast of Honduras. However, the local early warning system was activated and an evacuation from flood prone areas occurred that meant that no deaths occurred. Similar areas, where no local capacity building had taken place, experienced major mortality.(Global Water Platform, nd)). In the tsunami affected coastline of Tamil Nadu, India, communities where capacities in basic disaster management had been strengthened suffered substantially lower mortality than in communities where capacity development had not taken place (Government of India and UNDP, 2009).

_____ END BOX 8-2 HERE _____

While many approaches to risk reduction may be place- and hazard-specific, supporting more effective, better resourced and more accountable local governments thas the benefit of building generic adaptive capacity alongside hazard-specific response strategies (IFRC 2010). The uncertainty brought by climate change reinforces this message. Most fundamentally, this capacity includes access to information, the skills and resources needed to reflect upon and apply new knowledge, and institutions to support inclusive decisions-making. These are cornerstones of both sustainability and resilience. While uncertainty may make it difficult for decision-makers to commit funds for hazard-specific risk reduction actions, these barriers do not exist to prevent investment in the generic foundations of resilient and sustainable societies. Importantly, from such foundations local actors may be able to make better-informed choices on how to manage risk in their own lives, certainly over the short/medium terms. For instance, federations formed by slum dwellers have become active in identifying and acting on disaster risk within their settlements and seeking partnerships with local governments to make this more effective and larger scale (IFRC 2010).

While such mechanisms are important to *anticipate* future risk, there are huge accumulations of existing climate risk that are continuing to grow. Again, a wide range of experiences show that it is possible to at least partially address or *correct* this existing risk. Local level and community based disaster risk management programmes are now increasingly moving from a focus on strengthening preparedness and response to reducing local hazard levels (for example, through slope stabilization, flood control measures, improvements in drainage etc.) and to reducing vulnerability (strengthening and protecting existing buildings and local infrastructure; adopting new production systems in rural areas etc.); increasing resilience through instruments such as micro-insurance and finance or protecting or restoring critical regulatory ecosystem services (ISDR, 2009, P166-170; Lavell, 2009, Reyos 2010). Because they are locally based and often locally controlled, such programmes and processes tend to respond better to local conditions and needs, are more cost effective because they can access local knowledge and resources and build local ownership and most importantly build awareness and capacities. A growing number of examples now exist of community driven approaches that are supported by local and national governments as well as by international agencies, through mechanisms such as social funds and others (Bhattamishra and Barrett, 2008). However, most such experiences are still isolated, local and short term in character.

Various tools are used to design environmental and climate policies. Among them environment-energy-economy models produce long term scenarios taking into account demographic, technologic and economic trends. These scenarios can be used to assess consequences of various policies.These tools have limits and it is particularly difficult to model structural economic changes, as these models have been developed to represent marginal changes around reference scenarios. Introducing disasters within these models leads to specific issues, due to time and spatial scale inconsistency: these models have been developed to represent long term evolutions, while disasters are short term events; these models represent large region (supranational), while disaster consequences are highly heterogeneous and affect disproportionally small communities and subnational regions. However, at smaller spatial scales, models can help assess disaster consequences and, therefore, balance the cost of disaster risk reduction actions and their benefits. In particular, they can compare the cost of dealing with disasters with the cost of preventing disasters. Since disaster have intangible consequences (e.g., loss of lives, ecosystem losses, cultural heritage losses, distributional consequences) that are difficult to measure in economic terms, these models are necessary but to sufficient to decide about desirable policies and disaster risk reduction actions. Cost-benefit analysis is useful to compare costs and benefits. However, when intangibles play a large role and when no consensus can be reached on how to value these intangibles, other decision-making methods can be used. Multicriteria decision-making and robust decision-making are examples of such alternative decision-making methodologies.

Risk transfer schemes, such as insurance, reinsurance, catastrophe pools and bonds, parametric and micro insurance and other mechanisms, do not anticipate or reduce risk *per se* but can increase resilience at the national, local and household level. Many obstacles to such schemes still exist particularly in low income and many middle income countries: including the absence of comprehensive risk assessments, legal frameworks and the necessary infrastructure and probably more experience is required to determine the contexts in which they can be effective (Cummins and Mahul, 2008; Mahul and Stutley, 2010).

This capital of local initiatives to address risk to climate extremes is key to a sustainable future. Its effectiveness has been demonstrated in various cities in Latin America (IFRC 2010). But to unlock this potential for all urban areas requires a radical change in the culture of public administration and investment in most nations. While local communities can address certain issues with their own resources, the installation or upgrading of infrastructure, for example, requires investments and planning at the level of local, city or national governments. Correcting risk, therefore will only be possible in the context of a new culture of partnership between civil society, local and national governments and with major investments to reduce the development deficit in high risk urban and rural areas. While the investments required are potentially huge, working in a way that empowers local communities can lead to a radical reduction in costs. Above all, it can lead to a fundamental change in the dynamics of the political relationships between those at risk and those who control the resources required to address risk that holds the key to a more sustainable future.

8.6.2. Policies and Actions for Achieving Multiple Objectives

Managing the risks associated with climate extremes requires national, political commitment at the highest level and the transformation of the existing disjointed frameworks and mechanisms to address into a coherent overarching policy framework of the *state*. Unless such a policy framework is adopted, is backed by appropriate political authority, legislation and resources, it is difficult to see how existing mechanisms, organized around emergency management or environment offices in governments will be able to address multiple challenges. Policies and actions to achieve multiple objectives include stakeholder participation, participatory governance (IRGC, 2009, 2009a), capacity-building, and adaptive organizations.

The central issue is usually potentials to increase the likelihood of effective action by both increasing potential payoffs and broadening constituency support for a policy strategy and implementation approach by assuring that it benefits multiple agendas: e.g., resilience to *future* climate change extremes, reduced stresses on *existing* systems, prospects for economic and social development, and prospects for both economic and environmental sustainability. One of the ways to work toward the “bundling” of multiple objectives is to broaden participation in strategy development and action planning, both to identify multiple objectives and to encourage attention to mutual co-benefits. Although practices and traditions for such stakeholder participation differ across cultures, there is a considerable knowledge base reflecting both research and practice to use as a starting point (e.g., NRC, 2008). A second approach is to emphasize capacity-building of several kinds: capacities of multiple groups to identify and assess pathways for achieving objectives, capacities of local expertise to represent and communicate the existing knowledge, and capacities of decision-makers to incorporate knowledge and diverse views into coherent strategies for action (references). A third approach is to promote the development of adaptive organizations: organizations that are not so locked into rigid agendas and practices that they cannot consider new information, new challenges, and new ways of operating (Berkhout et al., 2006). Organizations that can monitor environmental, economic and social conditions and changes, respond to shifting winds of policy and leadership changes, and take advantage of opportunities for innovative interventions are a key to resilience, especially with respect to conceivable but long-term and/or relatively low-probability contingencies. Characteristics of adaptive organizations are relatively well-known (e.g., references), but examples of developing and sustaining such organizations are more difficult to find.

The principles of adaptive management have shown some success in promoting sustainable natural resource management under conditions of increased uncertainty that are to be expected with climate change (Medema et al, 2008). These principles include intentional procedural or technical experimentation and observation in real-time to compare the responsiveness of alternative management strategies to emerging risks. The underlying concept is to promote organisational arrangements that are capable of evolving over time as risk landscapes change. This has huge potential application for managing disaster risk under climate change and can build on solid foundations of reflexivity that already exist in the humanitarian sector. A methodological framework for facilitating anticipatory learning processes to manage for resilience is presented by Tschakert and Dietrich (2010). This research emphasizes the conceptual similarities and overlaps between resilience approaches and action research/learning approaches, and considers the implications for climate change adaptation (see Table 8-1). Evidence suggests that many of the challenges of adaptive management are common to other risk management and development approaches that seek to incorporate or be led by community actors. Such challenges are most well studied in international development contexts (eg Mungai et al., 2004) and often revolve around the distribution of power between local and management actors worked out through the division of labour and responsibilities, and control of information and decision-making rights (Pelling, 2007).

[INSERT TABLE 8-1 HERE:
Table 8-1: Conceptual similarities and overlaps between the resilience framework and participatory action research/learning (AR/AL), implications for learning, and examples for climate change adaptation. Source: Tschakert and Dietrich, 2010.]

Learning in the humanitarian sector takes place through a range of initiatives, some is sector-wide (e.g., ALNAP), learning is also structured around the internal needs of organisations (e.g., Red Cross) or the outcomes of individual events (e.g., DEC reviews of humanitarian practice including the Indian Ocean Tsunami). All have different methodologies, target audiences and frames of reference have all have led to practical and procedural changes. Less well developed is active experimentation in the field of practice with a view of proactive learning. This is difficult in the humanitarian sector where stakes are high and rapid action has typically made it difficult to implement learning-while-doping experiments. More generally adaptive management is a challenge for those organisations that perceive reputational risk from experimentation in the knowledge that some local experiments will be seen to fail (Fernandez-Gimenez et al., 2008). Where this approach works best outcomes have gone beyond specific management goals to build trust between stakeholders a resource that is fundamental to any policy environment facing an uncertain future.

8.6.3. Tradeoffs in Decisionmaking

Decision-making related to both disaster risk reduction and climate change adaptation involves political, economic, social and cultural tradeoffs, which are related to differences in values, interests, and goals for the future, and mediated through power relations. The ethical implications of these tradeoffs are increasingly discussed, both in terms of intra- and inter-generational equity (Gardiner, 2006). Questions of justice and fairness have been raised, including the need to rethink social contracts to redefine rights and responsibilities in a changing climate (Pelling and Dill, 2008; O'Brien et al., 2009; Dalb,y 2009; Brauch, 2009).

Tradeoffs and conflicts between economic development and risk management have been discussed in the literature (Kahl, 2003, 2006). The current trend of development in risk-prone areas (e.g., coastal areas in Asia) is driven by socio-economic benefits yielded by these locations, with most benefits usually to the private investors.. For example, export-driven economic growth in Asia favours production close to large ports to reduce transportation time and costs. Consequently, the increase in risk has to be balanced againstthe socio-economic gains of development in at-risk areas. Additional construction in at-risk areas is not unacceptable a priori, but has to be justified by other benefits, and sometimes complemented by other risk-reducing actions (e.g., early warning and evacuation, improved building norms, specific flood protection) (references).

Another example of trade offs linked to climate change and development is the future need for additional protection in historical city centres and touristic areas. When considering additional protection (e.g., dikes and seawalls) in historical centres, the building costs of protection will not be the only component to take into account. Aesthetic impacts of protections and consequences on city attractiveness will be central in decision-making (references). If, for example, buildings have to be modified in Paris to make them better able to cope with the high temperatures that are expected by the end of the 21st century, the city will have to be deeply modified. Today, very strict rules are in place to maintain the traditional architecture and urbanism of Paris, and adaptation targets will conflict with cultural heritage protection. Because of difficulties to attribute values to cultural assets, cost-benefit analyses based on economic assessments of costs and benefits is not the best tool to approach these type of problems. Multi-criteria decision-making tools have been developed to help make these trade-offs (references). Because these trade-offs imply political, ethical, and philosophical aspects, participatory approaches can be useful (references).

During disaster reconstruction it is important to balance speed with sustainability, and strong leadership with participatory approaches may result in a longer timeframe to reach decisions, but the decisions may better reflect local values as well as integrate scientific and wider strategic concerns (references). Yet it is important not to romanticise local actors or their viewpoints, which might at times be unsustainable or point to maladaptation or to accept local voices as representative of all local actors (references). When successful, participatory reconstruction planning has been shown to build local capacity and leadership, bind communities and provide a mechanisms for information exchange with scientific and external actors. As part of any participatory or community based reconstruction, the importance of a clear conflict resolution strategy has been recognized (references). To manage trade-offs and conflicts is an open, efficient, and transparent way, institutional and legal arrangements are extremely important. (Add examples (e.g., the Netherlands) and various existing legal schemes.

8.6.4. Addressing Multiple Scales

Different geographic scales of action tend to have different potentials and different limitations. Local scales offer potentials for bottom-up actions that assure participation, flexibility, and innovativeness, while large scales offer potentials for top-down actions that assure resource mobilization and cost- sharing. Integrating these kinds of assets across scales is often essential for resilience to climate extremes, but in fact integration is profoundly impeded by differences in who decides, who pays, and who benefits; and perceptions of different scales by other scales often reflect striking ignorance and misunderstanding (Wilbanks, 2007). In recent years, there have been a number of calls for innovative co-management structures that cross scales in order to promote sustainable development (e.g., Brasseurs and Rosenbaum, 2003; Cash et al., 2006; Sayer and Campbell, 2006).

What might be done to realize potentials for integrating actions at different scales, to make them far more complementary and reinforcing? In many cases, the experience to date suggests that initiatives undertaken at relatively large scales – at least in government – often discourage local agency by bogging down relatively localized (sectoral as well as geographic) action in bureaucratic requirements as a condition for access to financial and other resources. Top-down sustainability initiatives are often preoccupied with *input* accountability, such as criteria for partner selection and justifications (often based on relatively detailed quantitative analyses of such attributes as "additionality"), rather than on *outcome* metrics such as whether the results make a demonstrable contribution to sustainability (regarding metrics, see NAS, 2005).

At the same time, efforts to develop initiatives from the bottom up are often limited by a lack of information, limited resources, and limited awareness of larger-scale deriving forces. One study, for example, concludes that what local agency needs in order to initiate significant actions for greenhouse gas emission reduction are several conditions: 1) growing evidence of impacts on that locality of climate change; 2) policy interventions that directly or indirectly associate emission reductions with incentives and assistance for local innovation; and 3) technology alternatives appropriate to local conditions (AAG, 2003). Meanwhile, actions at local scales can undermine larger-scale initiatives through political opposition or downright obstruction, by passive resistance such as a denial of useful information, and/or by local redirections.

The challenge is to find ways to combine the strengths of both scales rather than having them work against each other (Wilbanks, 2007). Consider, for example, certain strengths offered by both internal and external assets for relatively local-scale climate change adaptation initiatives. Internally from a local perspective, factors of importance include wealth (or the lack of it), a capacity for collective social action (or the lack of it), economic diversification (or the lack of it), and local leadership (or the lack of it). Externally, factors of importance include linkages that expand the range of alternatives for the locality: financial and human resources, commodities, information; structures that enable adaptive responses such as market an non-market incentives and mechanisms for coordination; risk-sharing approaches such as insurance; and portfolios of locally-appropriate technologies.

For the development of proactive strategies, policies and measures on climate change adaptation and disaster risk reduction call for close cooperation between the scientific and the political communities. But the translation of new scientific and technological knowledge into binding policy decisions is time-consuming. To obtain the political support it is necessary to declare them as security issues of utmost importance that require extraordinary measures (Waever 2008; 2008a). This needs a horizontal coordination between international organizations, national ministries and local stakeholders, as well as both bottom-up and top-down approaches with close vertical cooperation across different levels.

8.6.5. Role of Actors and Agency

The challenge of addressing disaster risk reduction and climate change adaptation in a manner that promotes resilience and sustainability requires more than a haphazard approach. It calls for changes at all levels – by governments, civil society, individuals, and the private sector. These changes may potentially include new ways of thinking about social contracts, which describe the rights and responsibilities between these different parties. Pelling and Dill (2009) describe the ways that current social contracts are tested when disasters occur, and how disasters may open up a space for social transformation. The concept of resilience, which emphasizes the dynamics, linkages, and complexity of coupled social-ecological systems, can contribute to new ways of thinking about rights and responsibilities between states and citizens in the context of climate change, including new approaches to social contracts (O'Brien et al., 2009). In particular, lessons from research on resilience points to the importance of including a wider group of stakeholders interacting across different levels to address the dynamics and complexity of climate change. Facilitating cross-scale interactions as described above may call for coalition building or deliberative democracy. In any case, the hierarchical structures that have traditionally governed social contracts may no longer be effective, and new types of arrangements may be needed to reach the goals of resilience and sustainability (O'Brien et al., 2009). Pelling (2010) suggests that the potential for climate-related disasters opens for new understandings of identity and social organization that may present alternatives to established social contracts.

Means of improving connections between science and decision-making where decisions have a significant scientific component has been a topic of interest for many decades , including research attention as well as experiments in practice. For example, a recent report by the U.S. National Research Council on *Informing Decisions in a Changing Climate* (NRC, 2009) concluded that effective decision support involves six principles: begin with user needs, give priority to process over product, link information producers and users, build connections across disciplines and organizations, seek institutional stability, and design processes for learning. Particularly important was a finding that promoting science for decision-making requires iterative interaction between information providers and information users, not just one-way science communication.

A particular challenge in fields such as climate change is the treatment of uncertainties about what may lie ahead (references). On the one hand, communicating uncertainties to decision-makers about climate change extremes can have the effect of discouraging actions that might require resources or cause political controversy. On the other hand, failing to communicate uncertainties would be scientifically questionable. The fact is that decision-makers from individuals to national leaders make decisions constantly in the face of uncertainty, and in most cases they distrust messages from science that appear to claim certainty. Communicating uncertainties without impeding actions is an important aspect of science for society. Current knowledge indicates that the treatment of uncertainty in communications between science and decision-making needs more iterative interaction than is usually the case. It also needs to recognize that decision-makers differ greatly in their time horizons and their ways of coping with risks, and approaches for communicating uncertainty should be sensitive to different decision-making contexts.

Disaster risk reduction and sustainability policies have large policy implication (e.g., on inequalities). As a consequence, science alone cannot decide which policies are desirable, and political processes are necessary. These processes have to include scientific information and political choices. Different approaches have been implemented to include these two aspects, like working groups involving experts, stakeholders, and decision-makers. Examples can be provided on climate change management.

8.7. Synergies between Disaster Risk Reduction and Climate Change Adaptation

Drawing on the discussions presented in this chapter, it becomes clear that there are many potential synergies between disaster risk reduction and climate change adaptation that can contribute to a resilient and sustainable future. There is, however, no single approach, framework or pathway to a sustainable and resilient future; a diversity of responses to extremes taken in the present can contribute to future resilience in situations of uncertainty. Nonethless, there are some important factors that can contribute to risk reduction and sustainability. Four critical factors identified by Tompkins, Lemos and Boyd (2008, p. 736) that have been discussed in this chapter include 1) flexible, learning-based, responsive governance; 2) committed, reform-minded and politically active actors; 3) disaster risk reduction integrated into other social and economic policy processes; and 4) a long-term commitment to managing risk.

However, there are many gaps and barriers to realizing synergies that can and should be addressed to foster a resilient and sustainable future. For example, overcoming the current disconnect between local risk management practices and national institutional and legal frameworks, policy and planning can be considered key to reconciling short- term and long-term goals for vulnerability reduction. Reducing vulnerability has, in fact, been identified in many studies as perhaps the most important prerequisite for a resilient and sustainable future. In fact, some research has concluded that disaster risk reduction must be combined with structural reforms that address the underlying causes of vulnerability and the structural inequalities that create and sustain poverty, constrain access to resources, and threaten long-term sustainability (Lemos et al., 2007; Pelling, 2010). Globally, disaster mortality levels drop when countries' development indicators improve, particularly in rural areas (ISDR, 2009). There have been major documented reductions in drought, flood and cyclone mortality in rural areas (CRED, year?). These are due to a combination of improved development conditions (for example, flood mortality drops dramatically when transport infrastructure to permit evacuation exists and when health services are available), disaster preparedness, and early warning and response (which are also characteristic of improved development conditions).

Actions to reduce disaster risk and responses to climate change invariably involve trade-offs with other societal goals, and conflicts related to different values and visions for the future. Innovative and successful solutions that combine multiple perspectives, differing worldviews, and contrasting ways of organizing social relations has been described by Vermeij et al. (2006) as "clumsy solutions." Such solutions, they argue, depend on institutions in which all perspectives are heard and responded to, and where the quality of interactions among competing viewpoints foster creative alternatives. Drawing on the development ethics literature, St. Clair (2010) notes that when conflict and broad-based debate is forged, alternatives flourish and many potential spaces for action can be created, tapping into people's innovation and capacity to cope, adapt and build resilience. Pelling (2010) stresses the importance of social learning for transitional or transformational adaptation, and points out that it requires a high level of trust, a willingness to take risks, transparency of values, and active engagement of civil society. Committing to such a learning process is, as Tschakert and Dietrich (2010) argue, preferable to alternatives because "Learning by shock is neither an empowering nor an ethically defensible pathway."

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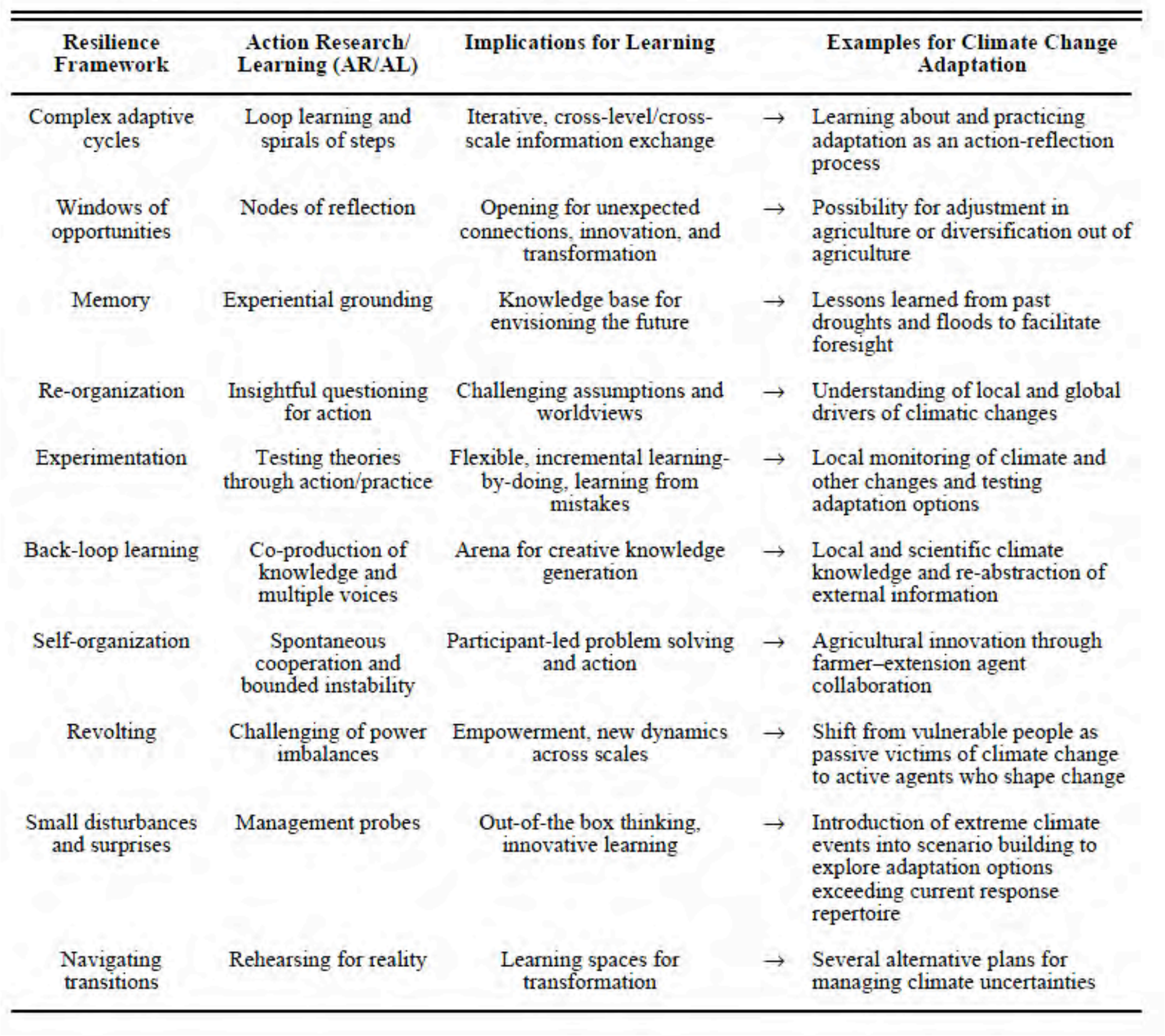
Table 8-1. Conceptual similarities and overlaps between the resilience framework and participatory action research/learning (AR/AL), implications for learning, and examples for climate change adaptation. Source: Tschakert and Dietrich, 2010.



Resilience Framework	Action Research/ Learning (AR/AL)	Implications for Learning		Examples for Climate Change Adaptation
Complex adaptive cycles	Loop learning and spirals of steps	Iterative, cross-level/cross-scale information exchange	→	Learning about and practicing adaptation as an action-reflection process
Windows of opportunities	Nodes of reflection	Opening for unexpected connections, innovation, and transformation	→	Possibility for adjustment in agriculture or diversification out of agriculture
Memory	Experiential grounding	Knowledge base for envisioning the future	→	Lessons learned from past droughts and floods to facilitate foresight
Re-organization	Insightful questioning for action	Challenging assumptions and worldviews	→	Understanding of local and global drivers of climatic changes
Experimentation	Testing theories through action/practice	Flexible, incremental learning-by-doing, learning from mistakes	→	Local monitoring of climate and other changes and testing adaptation options
Back-loop learning	Co-production of knowledge and multiple voices	Arena for creative knowledge generation	→	Local and scientific climate knowledge and re-abstraction of external information
Self-organization	Spontaneous cooperation and bounded instability	Participant-led problem solving and action	→	Agricultural innovation through farmer–extension agent collaboration
Revolting	Challenging of power imbalances	Empowerment, new dynamics across scales	→	Shift from vulnerable people as passive victims of climate change to active agents who shape change
Small disturbances and surprises	Management probes	Out-of-the box thinking, innovative learning	→	Introduction of extreme climate events into scenario building to explore adaptation options exceeding current response repertoire
Navigating transitions	Rehearsing for reality	Learning spaces for transformation	→	Several alternative plans for managing climate uncertainties

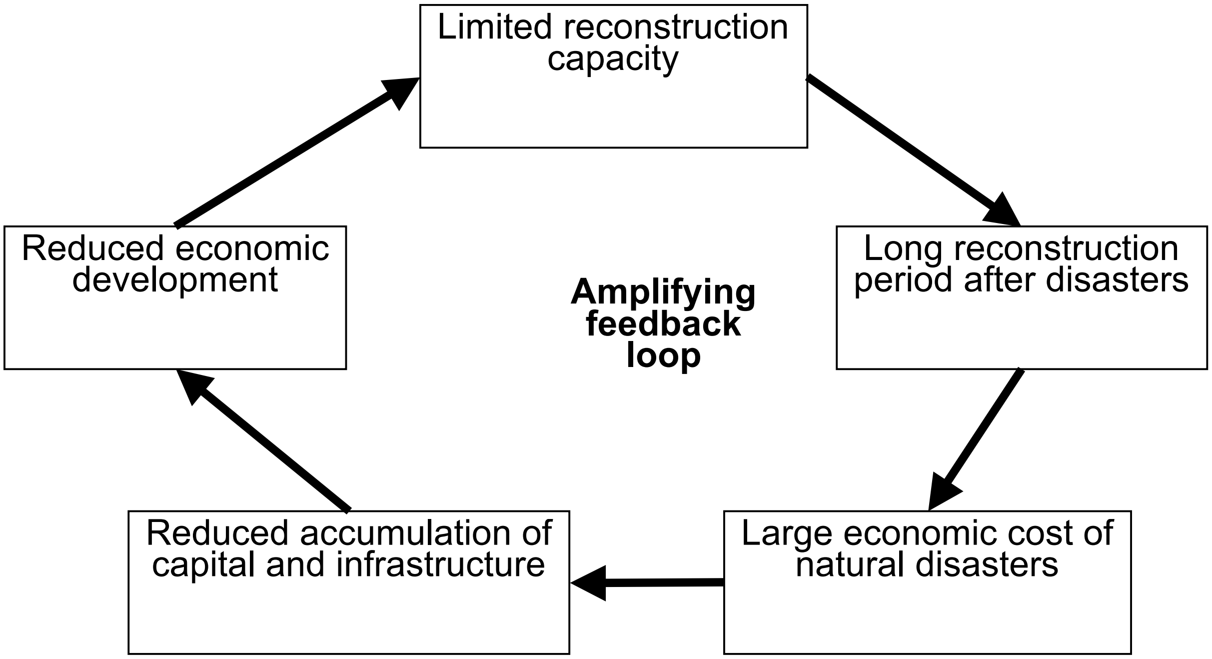


Figure 8-1: Amplifying feedback loop that illustrates how natural disasters could become responsible for macro-level poverty traps.

Chapter 9. Case Studies

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Contents

9.1. Introduction

9.1.1. *Description of Case Studies Approach in General*

This section seeks to convey the value of case studies in identifying lessons and good practices from past responses—in this case to extreme climate-related events. Case studies are widely used in many disciplines including health care (Keen and Packwood, 1995; McWhinney, 2001) and social science (Flyjberg, 2004), especially in political science, anthropology, comparative sociology and education (Verschuren, 2003). It is reported that case studies are the most popular research method used by industrial marketing researchers (Easton, 2010). In addition case studies have been found to be useful in previous Intergovernmental Panel on Climate Change (IPCC) Assessment Reports including the 2007 report (Parry et *al.,* 2007).

Case studies are often perceived to be among the most interesting articles to read (Eisenhardt and Graebner, 2007) possibly because they challenge readers' assumptions and have practical implications; interesting reading in turn produces a higher degree of learning (Bartunek et *al*., 2006). Case studies have been defined as 'research situations where the number of variables of interest far outstrips the number of data points' (Yin, 1994). Keen and Packwood consider that case study evaluations are valuable where broad, complex questions have to be addressed in complex circumstances often using multiple methods. They go on to state that the case study is a way of thinking about complex situations which takes the conditions into account but is nevertheless rigorous and facilitates informed judgments about success or failure (Keen and Packwood, 1995).

Indeed case studies seek to study phenomena in their real life context, not independent of context, and offer an opportunity to report an event from the 'ground' or from the 'front line'. Thus case studies are suitable for studying highly complex phenomena (Nyame-Asiamah and Patel, 2009) and analyzing extreme events allowing lessons to be identified and good and bad practices to be determined. For example many everyday decisions by health care professionals are qualitative rather than quantitative (Keen and Packwood, 1995) but directing them to the best evidence such as the Cochrane Collaboration for these decisions may reduce poor decision making (Jadad and Hanes, 1998).

Case studies can be records of innovative or good practice. Specific problems or issues experienced can be documented as well as the actions taken to overcome problems. Case studies validate our understanding or can encourage their re-evaluation. Often they are used where there have been limited solutions found to a particular problem and can identify success/failure factors in DRR[1] and adaptation. Case studies generally report factual information as well as opinions (good and bad). Their strengths include:

- Provide real examples
- Encourage replication
- Are generally practical in nature
- Provide innovative ideas (Twigg, 2001).

Therefore case studies should use concrete examples of disasters types; share prevention and preparedness methodologies and subsequent response and recovery actions because they provide useful insights into the practical application of prevention and risk reduction measures.

[INSERT FOOTNOTE 1 HERE: New South Wales Australia Department of Environment, Climate Change, and Water. Characteristics, strengths, and weaknesses - Case studies web site <http://www.environment.nsw.gov.au/community/edproject/section404.htm>.]

9.1.2. *Case Study Analyses: Lessons Identified and Learned – Good and Bad Practices*

Good storytelling or case studies are useful as a first step to explain issues but good theory is fundamentally the result of rigorous methodology and comparative multi-case logic (Eisenhardt, 1989). By describing the interpretation of cases studies, Leiberson demonstrated that they need rigorous justification of assumptions to guard against possible distortions (Lieberson, 1991). Most case study research points to the preparations for such research not to the benefit obtained from using case studies to illustrate issues identified by studies.

Case studies must be methodologically rigorous and include external validation. Fundamental quality measures will improve their reliability (Gibbert et *al.,* 2008). Verschuren reported that case study design should include observation of patterns in a diachronic (over time) manner, represent a strategic sample, and is labour intensive, open ended and iterative. Bozeman and Klein reported that policy evaluators and other social scientists often approach case studies with considerable wariness (Bozeman and Klein, 1999). They stated that case studies if properly deployed for heuristic purposes should be based on the explicit examination of the event with critical assessment to determine if the data is unique or illustrative of the wider dataset. Yin has documented the desired characteristics of case studies and recommended that sources of evidence be focused in an operational framework (Yin, 1999).

Woodside, using industrial marketing techniques, points to the principal criticisms of case study research studies. These include needing to fulfill generality of findings, achieving accuracy of process actions and outcomes, and capturing complexity of nuances and conditions in order to achieve clarity in processes involving decisions and organizational outcomes (Woodside, 2010).

A comparative study of real-life cases is then a way to check fact whether our understanding of a problem or solution (based on theory) is correct in reality and in various settings.

9.2. Methodological Approach

9.2.1. Case Studies

This chapter seeks to gain a better understanding of the threat posed by extreme climate-related events, while identifying lessons and best practices from past responses to such occurrences. To achieve these goals, several events, vulnerable regions and management approaches were identified and examined to gain a better understanding of the threats that extreme events pose and the most successful prevention and response measures. Specifically, case studies examining specific extreme events were: cyclones; urban heat waves; sandstorms; floods; drought, drought-heat-fires complex events; cold spells; and epidemics. Case studies focusing on vulnerable regions included: coastal and mega-cities; small island developing states (SIDS); Arctic regions; and least developed countries and fragile states. The third grouping looked at management approaches: risk transfer; public education and awareness; institutional approaches-multi-level governance; legislative approaches; hard and soft engineering in coastal zones; linking disaster risk reduction (DRR) and climate change adaptation (CCA) practices; and early warning systems. This selection created a good basis of information and served as an indicator of the resources needed for future disaster risk reduction. Additionally, it allows good and bad practices to be determined and lessons to be extracted.

As Margareta Wahlström asserts, “the real tragedy (of disasters) is that many of these deaths can be avoided” (Wahlström, 2009). To that end, the analysis of case studies is essential to the Special Report on Extreme Events and Disasters: Managing the Risks, due to the lessons they provide about best and worst practices, which will contribute to future disaster risk reductions. Further, the case studies provide the opportunity for connecting common elements across the other chapters. As the ICSU Report, *A Science Plan for Integrated Research on Disaster Risk* (2008) explains, despite a growth in knowledge surrounding environmental hazards, losses from these events have also increased. In other words, despite an increase in scientific knowledge, disasters still occur. This emphasizes the need for an integrated approach that examines scientific, social, economic and political aspects of disasters and broadens the scientific realm to include different spatial and temporal scales. Analyzing case studies of extreme events allows lessons to be identified and good and bad practices to be determined. Specifically, successful cases are compared in an effort to isolate the components necessary for success. Similarly, failed attempts are analyzed to determine the causes of failure. It is important to use concrete examples of disasters types; prevention and preparedness methodologies and subsequent response and recovery actions because they provide useful insights into the practical application of prevention and risk reduction measures. This is particularly important because there are sometimes gaps between the theoretical assumptions of what should succeed, and the practicality of what has succeeded or failed in the past. The study of these case studies lends greater context and understanding to the analysis completed in other chapters, thus contributing to value-added conclusions that will produce stronger, more effective disaster responses. Given that climate change can exacerbate extreme events and hazards, identifying good and bad practices will prove to be an important step for future risk reduction efforts.

9.2.2. Literature: Papers, Reports, Grey Literature

To properly assess the selected case studies, a variety of literature was studied including approaches that rely on resources from many disciplines and different types of literature. As noted above, an integrated approach that examines scientific, social, economic and political aspects of disasters and includes different spatial and temporal scales is needed and many of these aspects are covered in grey literature, materials that are not formally published or peer-reviewed. The specialized insight they provided was invaluable in evaluating the current disaster response practices. It is necessary to delve into such areas in order to create a more complete study of climate-related events.

Important primary resources were found in country-based reports focused on disaster accounting. These records included statistics on human life loss, financial damage, rebuilding costs and infrastructural weaknesses, as well as detailed accounts of rescue efforts. Further, they were able to provide information on level of preparedness, status of warning systems and any adaptation efforts. Additionally, resources from organizations such as the United Nations Development Programme, UNISDR, Amnesty International, or CARE proved especially useful as they provided an impartial account of the disaster as well as problems that emerged within relief efforts. Other sources such as articles from international journalists were helpful in providing the social or human costs that resulted from the extreme event.

The unpublished and un-peer-reviewed resources utilized in this study will be used in accordance with the IPCC regulations regarding grey literature. Specifically, each source was critically assessed by the authors to ensure an overall consistency with peer-reviewed sources. In the event of inconsistencies, additional methods of validation were employed. Used in this way, these resources provided accurate information that ensures the case studies will be useful learning tools.

9.2.3. Relationship between Extreme Climate-Related Events and Climate Change

The Intergovernmental Panel on Climate Change's 2007 Fourth Assessment Report (IPCC) has concluded that the "warming of the climate system is unequivocal"(IPCC 2007a, pg 5). As the temperature has warmed there have been increases in: frequency of warm spells/heat waves over most land areas; frequency of heavy precipitation events; area affected by drought; intense tropical cyclone activity; and increased incidence of high sea levels have arisen. The IPCC assessment was that it is likely, meaning greater than 66% probability, that these changes are a reality (IPCC 2007a, pg 3). The impacts of these events are highlighted by Wahlström (2009) who stated "*Over the last two decades (1988-2007), 76% of all disaster events were hydrological, meteorological or climatological in nature; these accounted for 45% of the deaths and 79% of the economic losses caused by natural hazards*." As the climate changes in the future there will be continued increases in the frequency and intensity of extreme events, as weather patterns change (UNISDR, 2008). The risks from climate hazards present a growing threat, especially to developing countries that lack the financial capacity or material resources to prevent disasters or mitigate their risks. (Laszlo, 2008). It is necessary to take these realities and relationships into account when planning prevention measures or instituting lessons learned. The interaction between extreme weather events and climate change is consistently referenced throughout the chapter as a reminder that older strategies may not work in the future and that infrastructure and disaster risk management plans need to be flexible to be effective. The overall objective of this report and ongoing research needs to be a legacy of an enhanced capacity and knowledge around the world to address climate-related hazards and make informed decisions on actions to reduce their impacts, such that in ten years, when comparable events occur, there would be a reduction in loss of life, fewer people adversely impacted, and wiser investments and choices made by governments, the private sector and civil society.

Additionally, the goals of disaster risk reduction and climate change adaptation are essentially the same- "reducing vulnerability to hazards" (IPCC Scoping Meeting for a Possible IPCC Special Report on Managing the Risks of Extreme Events to Advance Climate Change Adaptation, 2008, 4). Climate change adaptation is defined as "adjustment in natural or human systems in response to actual or expected climactic stimuli or their effects that moderates harm and exploits beneficial opportunities"[2]. Similarly, disaster risk reduction attempts to "minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards…"[3] Each discusses the need for preparation and prevention in order to escape the worst impacts of disaster. By administering the lessons learned in disaster risk reduction exercises, perhaps climate change adaptation will be more effective.

[INSERT FOOTNOTE 2 HERE: UN Framework Convention on Climate Change. Glossary. <http://unfccc.int/essential_background/glossary/items/3666.php>.]

[INSERT FOOTNOTE 3 HERE: UN International Strategy for Disaster Reduction. Terminology. <http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm>.]

9.2.4. Scale

This chapter addresses events whose impacts were felt on many dimensions. A single event can produce effects that are felt on local, regional, national and international levels. These could have resulted directly from the event itself, from the response to the event or indirectly through, for example, the reduction of food production in the region or a decrease in available oil. In addition to the spatial scales, this chapter also addresses temporal scales in both event-related impacts and responses. For example, some climate-related events such as a storm or hurricane last for a few days whereas others such as drought or sea-level rise occur and make their effects felt over a number of years. These factors are generally dependent on the magnitude and intensity of the event. However, the way effects are felt is additionally influenced by social and economic factors. The resilience of a society and its economic capacity to prevent a disaster and cope with the after-effects has significant ramifications for the intensity of the event (UNISDR, 2008). Developed nations are better equipped with technical, financial and institutional support to enable better adaptive planning including preventative measures and/or quick, effective responses (Gagnon-Lebrun and Agrawala, 2006). In developing nations in contrast, a less intense hazardous event can result in a disaster because their capacity to cope is so much lower (IPCC, 2001). The implications of factors such as location, development status, scale of disaster and response efforts in specialized communities, will make it easier for strategies to be applied in similar situations. Most importantly, this chapter recognized the complexity of disasters in order to encourage more solutions that address this complexity rather than just one issue or another.

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9.3. Case Studies

9.3.1. Extreme Events

Case Study 9.1. Tropical Cyclones

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1. Introduction

Tropical cyclones, also called typhoons and hurricanes, are powerful storms generated over tropical and sub-tropical waters. They are characterized by extremely strong winds, capable of damaging buildings and infrastructure; torrential rains causing floods and landslides; and high waves and storm surges that can lead to extensive coastal flooding. Due to their combined wind, rain and in some cases, cyclonic power, even relatively weak events can be destructive, as can be observed in the case of Typhoon Morakot in Taiwan. On 7 August 2009, Typhoon Morakot, classified as a category 1 cyclone, moved slowly toward Taiwan. Landing on the East coast of Taiwan at about midnight, the cyclone continued to travel, slowly dwindling in strength until it was classed as a tropical storm by mid-day on 8 August. Though Morakot did not exhibit extraordinary strength or power, moving approximately 30% slower than average and producing a relatively large gall wind radius of about 400km, it resulted in a record setting rainfall in Taiwan. Specifically, Morakot had the highest one-day precipitation (1624 mm), continuous two-day precipitation (2361 mm) and total accumulation over the duration of a typhoon (3060 mm, from 6 to 10 August 2009) ever recorded in Taiwan (Lin et al., 2010). In fact, its maximum single-day precipitation and continuous two-day precipitation were only about 10% less than the world records. The record amount of precipitation caused the worst flooding in Taiwan since 1959. As a result, close to 700 people lost their lives and more than ten thousand people were left homeless. Additionally, this downpour triggered an astonishing number of landslides. Approximately 51,300 landslides were recorded, more than twice the number observed in any previous individual event. In one case, a single landslide buried a village with about 400 inhabitants. Landslides seriously damaged nearly all roads in the central and southern mountains of Taiwan. Total damages to properties and infrastructures, and agricultural losses were estimated to be around US$ 3 billions.

The tropical cyclones considered in this case study demonstrate various issues related to the risk management practices and changing vulnerability of the exposed population over time and locations. In particular, the comparative studies clearly demonstrate that efforts towards disaster risk reduction can be effective in the context of adaptation to extreme events.

2. Sidr and Nargis: Comparison of Two Cyclones in Indian Ocean

Although only about 7% of the world's tropical cyclones occur in the North Indian Ocean (Muni Krishna, 2009), they account for 86% of global mortality risk from tropical cyclones (ISDR, 2009). This is largely due to high population density in exposed areas and poor governance in this region. Given that the historical tropical cyclone records exhibit existing trends in frequency and intensity in this region, the existing vulnerability is of particular concern (Muni Krishna, 2009, Singh et al., 2001). These trends must be considered cautiously, however, as there is still a lack of consensus regarding the heterogeneity of the data (Ch. 3, section 3.2.1; Landsea et al., 2006; Kossin et al., 2007). Despite this lack of consensus, the observed trends do carry some potential for representing future trends and the heightened exposure and potential for loss of life in this region makes it imperative that efforts are made to improve forecasting and mitigation. This point is especially important when considering that 80% of victims from Nargis were killed by storm surges for which there is currently no early warning system (Webster, 2008).

In 2007 and 2008, several cyclones with disastrous impact occurred in the North Indian Ocean. Two of these, namely Cyclone Sidr in 2007 (Paul, 2009), which mainly affected Bangladesh, and Cyclone Nargis in 2008 (Webster, 2008), which mainly affected Myanmar, were comparable events that had vastly different impacts. It is important to compare the two events in order to determine the reason why one was significantly more deadly than the other.

Sidr made landfall in Bangladesh on 15 November 2007. Its maximum wind speed reached 245 km/h and the storm surge reached between 5-6 m (Paul, 2009). Between 8 and 10 million people were exposed/affected and the number of reported fatalities was about 4,200 (PREVIEW, 2009; CRED, 2009). Conversely, Nargis hit Myanmar on 2 May 2008. Its maximum wind speed reached 235 km/h and the storm surge reached about 4 m (Webster, 2008). Between 2 and 8 million people were exposed/affected. The fatalities exceeded 138,000 (PREVIEW, 2009; CRED, 2009), making Nargis the eighth deadliest cyclone ever recorded (Fritz et al., 2009).

The difference between the two is evident in their level of preparedness and ability to respond in the aftermath of the events. Bangladesh has a significant historical record of large scale disasters and serious efforts to decrease risk from tropical cyclones have been made (Paul, 2009; Ch. 9, Case Study 18). The country experienced 15 disasters of more than 1000 casualties since 1960, including the infamous Cyclone Gorky (April 1991, causing about 140,000 fatalities) and the November 1970 Cyclone Bhola, which caused 300,000 (CRED, 2009) to 500,000 (Shamsuddoha and Chowdhury, 2007) deaths. After the devastating cyclone of 1970, the Bangladesh government initiated several structural and non-structural measures to reduce the cyclone risk (Paul, 2009). These measures, described more fully in Case Study 18, consisted of three major actions:

a) Implementation of an early warning system, including an extensive, equipped and trained group of volunteers
b) Construction of close to 4,000 public cyclone shelters
c) Construction of shelters to provide protection for cattle during storm surges.

Environmental features also played an important role in limiting the impact of Cyclone Sidr. The 590,000ha of the Sunderban mangroves and coastal forests proved to be effective barriers during the event (GoB, 2008). In Bangladesh, a coastal reforestation program was initiated in 1960, covering about 159,000ha of coastal land, the riverine coastal belt, and abandoned embankments. These plantations reduced the impact of previous cyclones and floods in addition to creating employment opportunities (GoB, 2008). Cyclone Sidr demonstrated that coastal reforestation protects embankments against cyclonic surge and monsoon waves – with the tremendous additional benefit of greatly reducing the impact of the storm surge (GoB, 2008).

In contrast to Bangladesh, Myanmar has very little experience with previous natural disasters. Prior to Nargis, Myanmar had only experienced one tropical cyclone disaster with more than 1000 fatalities since 1960 (CRED, 2009). The landfall of Nargis was the first time that Myanmar had experienced a cyclone of such a magnitude and severity (Lateef, 2009) and the path the storm took added to the degree of destruction (Webster, 2008). Several unfavourable conditions joined hands to transform this hazardous event into a large-scale disaster. First, there was virtually no early warning for this event. The Indian meteorological department has the responsibility to issue cyclone warnings for the region, but has no mandate to provided storm surge forecasts (80% of the victims from Nargis were killed by the storm surge). Myanmar's official forecasts appeared on page 15 in the newspaper The New Light of Myanmar from 29 April to 2 May, suggesting that the media underestimated the potential impacts of the threat, which resulted in insufficient warning to the population (Webster, 2008).

Despite being slightly less powerful than Sidr and affecting fewer exposed people, Cyclone Nargis resulted in human losses that were 32 times higher than Sidr. Bangladesh and Myanmar are both very poor countries. In 2008, the estimated GDP/population for Bangladesh was $1,500, while it was $1,200 for Myanmar (CIA, 2009). The relatively small difference in poverty (20%) cannot explain the discrepancy in the outcome. The World Bank has developed a series of indicators on governance (World Bank, 2009). These indicators suggest significant differences in the quality of governance between Bangladesh and Myanmar notably: Voice and accountability, Rule of Law, Regulatory quality, and Government effectiveness. The low quality of governance, and low level of accountability were highlighted as major components of human mortality risk with respect to tropical cyclones (Peduzzi et al., 2009).

3. Stan and Wilma: Comparison of Two Hurricanes in Mesoamerica

Hurricane Stan hit the Atlantic coast of Central America and the Yucatan Peninsula in Mexico (Mesoamerica) between the 1st and 13th of October 2005. It was associated with a larger non-tropical system of rainstorms that dropped torrential rains and caused debris flows, rockslides and widespread flooding. Guatemala reported more than 1,500 fatalities, El Salvador 72 and Mexico 98. Hurricane Wilma hit one week later (October 19-24th), with a diameter of 700km and winds reaching a speed of 280 km/h. It caused twelve fatalities in Haiti, eight in Mexico and thirty-five in the USA, most in Florida (National Hurricane Center, April 6, 2006). 560,000 residents in western part of Cuba and 90,000 tourists and local inhabitants in the Yucatan Peninsula in Mexico were evacuated during this event (EM-DAT, 2010).

A joint study by the World Bank with CEPAL and CENAPRED (the National Center for Disasters; García et al., 2006) evaluated socioeconomic damages in Mexico. The report shows that Stan caused about $2.2 billion damage in Mexico, 65% of which were direct losses and 35% impact on future productive activities (coffee, forestry and livestock). About 70% of these damages were reported in the state of Chiapas, where 40% of the natural vegetation of the Tuxtla Sierra was destroyed (Oswald Spring, 2010).

While Stan mainly hit the poor indigenous regions of Guatemala, El Salvador and Chiapas in Mexico, Wilma affected the international beach resort of Cancun. The damages caused by Wilma were estimated to be $1.74 billion, 25% of which were direct damage and 75% indirect costs due to lost economic opportunities. The damages caused by Wilma were mostly to the tourist sector. However, most of the affected and destroyed hotels were insured.

Comparing the management of the two hurricanes by the Mexican authorities, in the same month and year, highlights important issues in disaster risk management. The early alert for Wilma was quite effective: 98,000 people were evacuated, 27,000 tourists were brought to safer places, and 15,000 local inhabitants and tourists were taken to shelters. Before the hurricane hit the coast, heavy machines and emergency groups were situated in the region to re-establish water, electricity, communications and health services immediately. After the disaster, all ministries became involved in order to re-establish the airport and tourist facilities as soon as possible. By December, most hotels and the sand lost in the beaches were re-established. By comparison, the evacuation of Stan in Chiapas, Mexico started during the emergency phase, when floods in 98 rivers had affected 800 communities (Pasch and Roberts, 2006). About 100,000 people fled from the mountain regions; 84,000 lived in improvised shelters -mostly schools- and 1,200 affected families lived with “guest families”. In total, about 2 million people in Mexico were affected by this event. Over 80% of the damages were concentrated in four municipalities (Motozintla, Tapachula, Huixtla and Suchiate). They were rural, isolated in mountainous areas, marginal, indigenous, and most inhabitants were extremely poor and had little or no education. The cost of damages caused by Stan represented 5% of the GDP of the State of Chiapas and most of the productive infrastructure (75,000 hectares of coffee plantation) in the affected areas was destroyed (Calvillo et al., 2006). Emergency help was brought by ship, plane and cars, but the head of SEDESOL (Ministry of Social Development) in Chiapas, Luis Alberto Molina Rios, had to admit a year later that less than 10% of the 10,200 houses affected by Stan were rebuilt. The most common adaptation strategy was migration to urban areas or to the USA in search of a dignified livelihood

Comparing the two hurricane responses, it is obvious that the amount of federal attention given to the affected region contributed greatly to the ability of that region to respond. Regrettably, Cancun received much more attention and funding than Chiapas though the latter’s damages were more serious and the residents of that area were without insurance due to their high social vulnerability. Despite the similarity in strength of hurricane, each region felt the event differently due to the disparity in terms of early warning, evacuation and reconstruction efforts.

4. Typhoon Maemi’s Role in Korea’s Disaster Recovery Policies

The Northwest Pacific Ocean (NWPO) is the world's most prolific generator of tropical cyclones, producing about 6 to10 category 4 and 5 (in Saffir-Simpson scale) typhoons each year (WMO, 2004). These severe typhoons are direct threats to the half-billion people living in the coastal regions of East Asia (Lin et al., 2005).

Typhoon Maemi ('Cicada') formed as a tropical depression near Guam, east of the Philippines on 5 September 2003 and developed into a category 5 super-typhoon as it approached the southern Japanese islands of Okinawa (Guy Carpenter, 2003; Ye, 2004; Kim et al., 2007). It struck the south coast of the Republic of Korea during the night of September 12 as a category 3 typhoon, with wind gusts reaching 216 km/h (Kikitsu, 2004) and rainfall of up to 450 mm. Maemi was one of the most powerful typhoon to strike Korea since records began in 1904. The strong winds, storm surge and heavy rainfalls caused widespread damage throughout the country, severe flooding along the Nakdong River, and a number of debris flows and landslides with severe impacts (Met Eireann, 2003; Guy Carpenter, 2003; Ye, 2004; Kim et al., 2007; Chae et al., 2006). According to the Korean anti-disaster office, the total economic losses caused by Typhoon Maemi were about $4.8 billion.

After Typhoon Maemi, 116 petitions were gathered from people complaining that the post-disaster support process was not simple and fast enough. In response to these petitions, Korea has developed the One-Stop Support Service to increase the effectiveness of the disaster recovery support process. The One-Stop Support Service is a customer-oriented, rapid and precise system for providing support to the affected population after a natural disaster. In the case of typhoon Ewiniar in July 2006, the One-Stop Support Service was applied to the damaged areas and the recovery fund was directly transferred to affected individuals in 20 days, a process which normally took about 90 days. This kind of rapid money transfer helped the people focus on the recovery works (ADRC, 2007).

The Korea Meteorological Agency (KMA) has plans for strengthening its observational networks within three years. The aims of these plans are to improve the resolutions of Automatic Weather Stations (AWSs) from 15 km to 13 km; to establish 2 radar sites; to deploy 10 buoys; to build a Composite Site for Marine Meteorological Observation on an uninhabited island located at the westernmost tip of Korea; and to install 10 wind profilers across the county (Park, 2003). The improvements in the observational network will improve the efficiency and accuracy of typhoon warnings from the KMA in the future.

5. Lessons and Key Messages

Disaster management of the tropical cyclones discussed in this case study demonstrate that the *choices and outcomes for response to climatic extremes events are complicated by* ***multiple interacting processes****, competing prioritized* ***values*** *and* ***objectives***. The government response to similar extreme events may be quite different in neighbouring countries, or even within the same country.

Awareness (past occurrence of large scale disasters) and improved governance (implementation of improved early warning systems, evacuation plans, infrastructures, the protection of healthy ecosystems, post-disaster support service to disperse the recovery funds to the victims quickly and efficiently) are essential in coping with extreme tropical cyclone events.

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Case Study 9.2. Urban Heat Waves, Vulnerability and Resilience

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1. Introduction

In August of 2003, temperatures in much of Europe greatly exceeded historical norms. During the first 2 weeks of August 2003 much of Western Europe experienced daytime temperatures of 35°-40°C and night time temperature which did not drop below 20°C (Institut de Veille Sanitaire, 2003). This corresponded to an increase in monthly mean temperature of about +7°C (Fink et al., 2004). The European heat wave had significant health impacts (Lagadec, 2004): initial estimates put the death toll in the range of 70,000 (Robine et al, 2003) with approximately 14,800 excess deaths in France alone (Pirard et al., 2005). The severity, duration, geographic scope, and impact of the event were unprecedented in recorded European history (Fouillet et al., 2006; Grynszpan, 2003; Kosatsky, 2005) and put the event in the exceptional company of the deadly Beijing heat wave of 1743, which killed at least 11,000, and likely many more (Levick, 1859; Bouchama, 2004). Efforts to minimize the public health impact were hampered by denial of the events seriousness and the inability of many institutions to instigate emergency-level responses (Lagadec, 2004). Afterwards, several European countries quickly initiated plans to prepare for future events (WHO, 2006). France, the country hardest hit, initiated a national heat wave plan, surveillance activities, clinical treatment guidelines for heat related illness, identification of vulnerable populations, infrastructure improvements including air conditioning in nursing homes and hospitals, and home visiting plans for future heat waves (Laaidi *et al.*, 2004).

Three years later, during the last two weeks of July 2006, Europe experienced another major heat wave. Several temperature records were broken. In France, it ranked as the second most severe heatwave since 1950, with the first being the event in 2003. Based on historical models, the temperatures were expected to cause 6,452 excess deaths in France alone, yet, only 2,065 excess deaths were recorded (Fouillet et al., 2008). Some decrease in mortality may be attributed to increased awareness of the ill-effects of extreme heat, the preventive measures instituted after the 2003 heat wave, and the heat health watch system set up in 2004 (Fouillet et al., 2008). While the mortality reduction likely demonstrates the effectiveness of public health measures, the persistent, excess mortality highlights the need for optimizing existing public health measures such as warning and watch systems (Hajat et al., 2010), health communication with vulnerable populations (McCormick 2010), vulnerability mapping (Reid et al., 2009), and heat wave response plans (Bernard and McGeehin, 2004). It also highlights the need for other, novel measures such as modification of the urban form to reduce exposure (O'Neill *et al.*, 2009; Hajat et al., 2010; Reid et al., 2009; Bernard and McGeehin, 2004; Silva, Phelan and Golden, 2010).

2. Description of Thematic Events

As with other types of hazards, extreme heat can have disastrous consequences for populations with extreme vulnerability. Vulnerability is a function of hazard exposure and susceptibility to illness or injury. The magnitude of the hazard is important, as it drives exposure, but does not necessarily translate into extreme impacts if vulnerability is low. Extreme heat is already a prevalent public health concern throughout temperate regions of the world (Kovats and Hajat, 2008). Extreme heat hazards have been encountered recently in North America (Hawkins-Bell and Rankin, 1994; Klinenberg, 2002), Asia (Kalsi and Pareek, 2001; Srivastava et al., 2007; Kumar, 1998), Africa (McGregor et al.), and Australia (Victorian HHS 2009), and there is consensus that climate change is highly likely to increase the frequency of extreme heat events (AR4). It is important, therefore, to consider factors that contribute to hazard exposure and population susceptibility. Recent literature has identified a host of factors that can amplify or dampen hazard exposure. Experience with past heat waves and public health interventions suggests that it is possible to manipulate many of these variables to reduce both exposure and susceptibility and thereby limit the impacts that extreme heat hazards present.

3. Heat Wave Vulnerabilities

3.1. Understanding local vulnerability and working with communities to improve resilience

Several factors influence susceptibility to heat related illness and death. Physiologic factors, such as age, gender, body mass index, and pre-existing health conditions play a role in the body's ability to respond to heat stress. Older persons have a number of physiological and social risk factors that place them at elevated risk, such as decreased ability to thermoregulate (the ability to maintain temperature within the narrow optimal physiologic range) (Havenith, 2001). Pre-existing chronic disease, more common in the elderly, also impairs compensatory responses to sustained high temperatures, and certain medications may interfere with thermoregulatory mechanisms as well (Havenith, 2001; Shimoda, 2003). Many older adults tend to have suppressed thirst impulse. In addition, multiple diseases and/or drug treatments also increase the risk of dehydration (Hodgkinson, Evans and Wood, 2003; Ebi and Meehl, 2007). Older persons may also be more likely to be isolated and living alone than younger persons (Semenza, 2005; Naughton, et al., 2002). Babies and young children are at risk for adverse heat affects (Weiland 2004).

A wide range of socio-economic factors are also associated with increased susceptibility. Areas with high crime rates, low social capital, and socially isolated individuals increased vulnerability during the Chicago heat wave in 1995 (Klinenberg, 2002). People in low socioeconomic areas are generally at higher risk of heat-related morbidity and mortality due to higher prevalence of chronic diseases that increase risk, from cardiovascular diseases such as hypertension to pulmonary disease such as chronic obstructive pulmonary disease and asthma (Smoyer, Rainham, Hewko, 2000; Sheridan, 2003). Minorities and communities of low socio-economic status are more frequently situated in higher heat stress neighborhoods (Harlan et al 2006). Protective measures are often less available for those of lower socioeconomic status, or even if air conditioning is available, some of the most vulnerable populations will choose not to use it out of concern over the cost (O'Neill et al. 2004). Other groups, like the homeless and outdoor workers, are particularly vulnerable because of their living and working conditions. During the 2005 heat wave in Phoenix, Arizona, outdoor workers and the homeless had the highest burden of heat stroke mortality (Yip et al., 2008).

3.2. Adapting the urban infrastructure to improve resilience to extreme heat

It is particularly important to address these vulnerabilities in urban areas. About half the world's population live in urban areas at present, and by 2050, this figure is expected to rise to about 70 percent. Cities across the world are expected to absorb most of the population growth over the next four decades, as well as continuing to attract migration from rural areas (UN, 2008). It is projected there may be 27 mega-cities with populations of over 10 million by 2050, up from 19 today (WB, 2003). In the context of an extreme heat event, certain infrastructural factors can either amplify or reduce the vulnerability of exposed populations. The built environment is important since the urban thermal budget is affected by local heat production (from internal combustion engines, air conditioners, and other activities), surface reflectivity or albedo, the percent of vegetative cover, and thermal conductivity of building materials. The urban heat island effect, caused by increased absorption of infrared radiation by buildings and pavement lack of shading by vegetation and increased local heat production, can significantly increase temperatures in the urban core by several degrees Celsius, raising the likelihood of hazardous heat exposure for urban residents (Clarke, 1972; Shimoda, 2003). Research has also identified that, at least in the North American and European cities where the phenomenon has been studied, these factors can have significant impact on the magnitude of heat hazards on a neighborhood level (Harlan et al., 2006). One study in France has shown that higher mortality rates occurred in neighborhoods in Paris that were characterized by higher outdoor temperatures (Cadot, Rodwin, Spira, 2007). High temperatures can also affect transport networks when roads and railtracks are damaged by the heat. Within cities, outdoor temperatures can vary significantly, some work has found by as much as 5 degrees C (Konopacki and Akbari, 2001; Rosenzweig, Solecki 2005). Amplification of heat exposure varies between cities, as well, as sprawling cities – those with less dense development, a lower proportion of vegetative land cover, and more impervious surfaces – are warming at a faster rate than more dense urban areas (Stone et al., 2010).

Systems of power generation and transmission are also important in explaining vulnerability. Electricity supply underpins a significant adaptation strategy particularly in developed countries, but it is also at increased risk of failure during a heat wave. Demand increases as the need for refrigeration and air conditioning is felt more. Increases in emergency medical dispatch calls during periods of increased heat have been shown to place increased burden on multiple financial and human resources (Golden, et al., 2008). High emergency medical dispatch volumes related to heat stress are greatest at the same time as maximum demand for electricity, which also increases strain on power grids, increasing the potential for failure of a significant adaptation strategy (Gordon et al 2008; California Energy Commission, 2007). Power grids have failed due to strain from high electricity demand, most notably in the state of California and the cities of Chicago and New York. Areas with lower margins face increased risk of disruptions to generating resources and transmission under excessive heat events (North American Electric Reliability Council, 2006).

In addition to increased demand, there can be a risk of reduced output from power generating plants (UNEP, 2004). Inland nuclear power plants in particular face environmental restrictions on the temperature of the water they are allowed pour back into rivers, which affects their ability to cool the generators down. During periods of extreme heat, they may have to reduce their output or risk environmental damage. In Europe, nuclear reactors have already had to slow down or issue special temporary dispensations granted during periods of extreme heat, such as during the summer 2003 (Jowit and Espinoza, 2006; Pagnamenta, 2009). Additionally, there is the issue of long-term adaptation, like in the case of hydropower where fluctuating levels of water availability will determine energy outcomes. With projected changes to the hydrological cycle in the Phoenix, Arizona area amounts of water available for hydropower may decrease dangerously in the rapidly developing, energy-intensive metropolitan area (Environmental Protection Agency, 1998).

Several types of infrastructural measures can be taken to prevent negative outcomes of extreme heat events. Reducing energy consumption in buildings can improve resilience, since then localized systems are less dependent on vulnerable energy infrastructure. In addition, by better insolating residential dwellings, people would suffer less effect from extreme heat. Tax incentives have been trialled in some European countries as a means to increase energy efficiency by supporting people who are insulating their homes. Urban greening can also reduce temperatures, protecting local populations and reducing energy demands (Akbari 2001). Preparedness for extreme heat therefore requires environmentally-friendly land use planning (Myeong 2009). Models suggest that significant reductions in heat related illness would result from land use modifications that increase albedo, proportion of vegetative cover, thermal conductivity, and emmissivity in urban areas (Silva et al. 2010).

4. Role of Disaster Risk Reduction or Climate Change Adaptation

4.1. Reducing exposure

From a Disaster Risk Management (DRM) perspective, the risks associated with extreme heat hazards can be reduced by lowering the likelihood of exposure and reducing susceptibility. A common public health approach to reducing exposure likelihood is the Heat Warning System (HWS) or Heat Action Response System (HARS). The four components of the latter include an alert protocol, community response plan, communication plan and evaluation plan (Health Canada 2010). The HWS is represented by the multiple dimensions of the EuroHeat plan, such as a lead agency to coordinate the alert, an alert system, an information outreach plan, long-term infrastructural planning, and preparedness actions for the healthcare system (WHO 2009). There are a range of approaches used to trigger alerts and a range of response measures implemented once an alert has been triggered. Some jurisdictions rely on existing emergency plans when the most severe type of event is triggered. For many cities, there are separate plans that integrate actions as needed and address more modest heat wave events. In some cases, departments of emergency management lead the endeavor, while in others public health-related agencies are most responsible (McCormick *in press*). Heat warning systems are sometime only present in urban areas (e.g. in Canada) (Paszkowski, 2007). However, many cover both urban and rural areas (e.g. France, England and Wales).

There is very limited evidence on the effectiveness of the heat warning systems. A few studies have identified a reduced impact. For example, the use of emergency medical services dropped by 49% during a heatwave in

Milwaukee, Wisconsin, U.S.A. between 1995 and 1999, and were not entirely attributable to differences between two heat waves in those years (Weisskopf et al., 2002). Evidence has also indicated that interventions in Philadelphia could have reduced mortality rates by 2.6 lives per day during heat events (Ebi et al., 2004). An Italian intervention program found that caretaking in the home resulted in decreased hospitalizations due to heat (Marinacci et al., 2009). Following the 2003 heatwave, France developed the *"Plan Canicule,"* focused on prevention, responsibility, and solidarity. When a subsequent heat wave occurred in 2006, mortality rates were two to eight percent lower than expected mortality (Fouillet et al., 2008). However, for all these studies, it is not clear whether the observed reductions were due to the interventions. Questions remain about the levels of effectiveness in many circumstances (Cadot, Rodwin and Spira, 2007).

Philadelphia was one of the first US cities to begin a heat preparedness plan, and today has a ten-part program that has been economically beneficial and suggested as effective (Ebi et al., 2004). The primary components in Philadelphia is the integration of a pre-existing social program including home visiting for vulnerable communities (Sheridan, 2006). The program incorporates existing social capital by utilizing a "block captain" system where local leaders are asked to notify community members of dangerous heat (McCormick, 2010). Such programs that utilize social networks have the capacity to shape behavior since networks can facilitate the sharing of expertise and resources across stakeholders (Crabbé and Robin, 2006). Social networks that are a critical aspect of social capital do not always facilitate adaptive behavior, however, and can lead to contribute to vulnerability (Adger et al. 2010). Other heat warning systems, such as that in Melbourne, Australia, are based solely on alerting the public to weather conditions that threaten older populations (Nicholls et al., 2008). In Canada, a HARS was developed through participatory processes, including 1) community HARS Advisory Communities 2) conducting heat health vulnerability assessments, 3) conducting extreme heat simulation exercises 4) developing HARS communications strategies and 5) evaluating the systems.

Addressing social factors in preparedness promises to be critical for the protection of vulnerable populations. This includes incorporating communities themselves in understanding of and responses to extreme events. Top-down measures imposed by health practitioners that do not account for community-level needs and experiences are likely to fail. Greater attention to and support of community-based measures in preventing heat mortality can be more specific to local context, such that participation is broader (Semenza, 2006). Such programs can best address the social determinants of health outcomes.

4.2. Communication and education

One particularly difficult aspect of heat warning is health communication. This is particularly relevant for older adults who may depend on numerous tools and strategies to address their special needs (Aldrich and William, 2008). In many locations populations are unaware of their risk and heat wave warning systems go largely unheeded (Golding, 2009) (Luber and McGeehin, 2008). Developing appropriate educational messages about heat waves is a difficult task. Some evidence has even shown that top-down educational messages result in a very limited amount of resultant action (Semenza et al., 2008). The receipt of information is not sufficient to generate new behaviors or the development of new social norms. Even when information is distributed through pamphlets and media outlets, behavior of at risk populations often does not change, and those targeted by such interventions have suggested that community-based organizations be involved in order to build on existing capacity and provide assistance (Abrahamson, 2008). Older people, in particular, engage better with prevention campaigns that allow them to maintain independence and do not focus on their age, as many heat warning programs do (Hughes, Van Beurden, and Eakin, 2008). More generally, research shows that these programs should be centered around engaging with communities in order to increase awareness (Smoyer-Tomic and Rainham, 2001).

4.3. Assessing heat mortality

Assessing heat mortality presents particular challenges in itself. There are a number of estimates of mortality for the European heat wave that vary depending on geographic and temporal ranges, methodological approaches, and risks considered (Assemblee Nationale, 2004). Accurately assessing heat-related mortality faces challenges of differences in contextual variations (Poumadere et al., 2005; Hémon and Jougla, 2004) and coroner's categorization of deaths (Nixdorf-Miller, Hunsaker and Hunsaker, 2006).

The different types of analyses used to assess heat mortality, such as certified heat deaths and heat-related mortality measured as an excess of total mortality over a given time period, are important distinctions in assessing who is affected by the heat (Kovats and Hajat 2008). Learning from past and other countries' experience, a common understanding of definitions of heatwaves and excess mortality, and the ability to streamline death certification in the context of an extreme event could improve the ease and quality of mortality reporting.

5. Relationship to Key Messages

With climate change, heatwaves are likely to increase in frequency and severity in many parts of the world. Urban settings are especially susceptible to heatwaves, even, and possibly more so, in highly developed countries. Climate change adaptation will require smarter urban planning, improvements in existing housing stock and critical infrastructures, and effective public health measures. Disaster risk originates from a combination of social processes and their interaction with the environment. Social, biological, built environmental and infrastructural characteristics shape vulnerability to extreme heat events.

Effectively preparing for, responding to, and recovering from extreme events and disasters require understanding current and projected risks. The specificity of heat risks to particular sub-populations can facilitate appropriate interventions and preparedness.

Risk is a product of both exposure and vulnerability. The differences in mortality between the European heat waves in 2003 and 2006 reflect how interventions may reduce vulnerability over time, as well as the difficulty in measuring the efficacy of interventions aimed at reducing risk.

Risk is context specific and the result of local conditions of endangerment, global and historical root causes, and intervening dynamic pressures. Heat impacts are felt distinctly based on local context, and handled based on historical practices, adaptation to trends in temperature, institutional preparedness, and community engagement.

Long-term adaptation to climate extremes will require climate smart disaster risk management. By using the long-term impacts of climate change as a guide for planning in places where temperatures are projected to increase, adaptation can be developed appropriately and effectively.

6. Research Gaps and Needs

There is little understanding regarding the interrelationship between individual-level vulnerabilities and neighborhood-level characteristics such as built environment and social factors. Further research is needed in these areas.

Further research is needed on the effectiveness of existing plans, how to develop improved preparedness that specifically focuses on vulnerable groups, and how to best communicate heat risks across diverse groups. There are methodological difficulties in describing individual vulnerability that need further exploration.

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Case Study 9.3. Drought and Famine in Ethiopia in the Years 1999-2000

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1. Introduction

Historical accounts of droughts resulting in famines in Ethiopia go as far back as the 9th century however some evidence on health impact started to emerge from the 15th century onwards. Unfortunately, famine has been endemic in Ethiopia in the last few decades. The famine in 1973 claimed over 300,000 lives. In 1985, approximately ten million people were reported to be starving, with approximately 300,000 already dead and about 1000 dying daily. In the following years, droughts leading to food shortages have had local and national adverse health effects, in particular in 1999/2000 (Taye et al 2010).

Adverse climatic conditions such as droughts have caused major fluctuations in agricultural and economic growth, rendering the country one of the poorest in the world. The largest group of poor people in Ethiopia is small scale farmers. (World Health Statistics 2008) The impact of adverse climatic conditions has been exacerbated by, the improving yet still existing, underdeveloped farming technologies, transport and communication networks and environmental degradation (Ethiopia has one of the highest rates of soil nutrient depletion in sub- Saharan Africa). (International Fund for Agricultural Development 2008) The country is reported to be currently only irrigating about 6% (5.8%) of its irrigable potential with plans to improve this capacity by 2010. (World Health Statistics 2008) In 2007/2008, 60% (59.9%) of the population had access to safe water and coverage with latrines was 37%. (Federal Ministry of Health of Ethiopia 2008)

2. Meteorological Background

Drought is the consequence of a natural reduction in the amount of precipitation over extended period of time, usually a season or more in length, often associated with other climatic factors (such as high temperatures, high winds and low relative humidity) that can aggravate the severity of the event. (Sivakumar 2005) It is a normal event that takes place in almost every climate on Earth, even the rainy ones. Drought manifestation varies from region to region and therefore a global definition is a difficult task e.g. one might define drought in Libya as occurring when annual rainfall is less than 180 mm, if less than 2.5 mm of rainfall in 48 hours in USA, about 15 consecutive days with daily precipitation totals of less than 25 mm in GB, actual seasonal rainfall deficient by more than twice the mean deviation in India, but in Indonesia, Bali drought might be considered to occur after a period of only 6 days without rain. (Ragab 2005)

Ethiopia is particularly sensitive to periodic droughts due to changes in the rainfall pattern related to El Niño events in the Pacific and Indian oceans. Investigating the published rainfall patterns between 1979 and 2005 indicated that the main growing-season rainfall has diminished by about 15% in food-insecure countries clustered along the western rim of the Indian Ocean. Some have concluded that there are moisture deficits upstream in a warming Indian Ocean, is likely to result in further rainfall declines. (Funk et al 2008).

Drought is one of the main causes of global disasters and during the past 30 years there has been an increased frequency and intensity of this phenomenon in most regions in the world, according to the IPCC.

3. Geological and Demographic Background

The total population of Ethiopia in 2008 is estimated to be about 81,021,000 with a Gross National Income per capita (PPP international $) of $630 and a total expenditure on health per capita (Intl $, 2006) of $22 or as percentage of GDP (2006) $4.9. (World Health Statistics 2008) In Ethiopia, more than 85% of the country's population depend on agriculture as their primary source of income. (International Fund for Agricultural Development 2008) Ethiopian agriculture is reported as being dominated by a subsistence rain-fed farming system, which could render the livelihoods of those who depend on it, vulnerable to climatic conditions.

4. Events Summary

A Drought resulting in a famine has, inherently, a smouldering beginning. Periods of reduced rainfall silently turn into drought which turns into failing crops or forced sell-off of animals by pastoralists. The populations live on limited reservoirs of food or economic means and it slowly turns into a famine. International recognition of such a famine than requires a great number of steps again. During 1999/2000, great parts of Ethiopia experienced a period of famine which was recognised internationally. To illustrate the effects a specific study on a typical area is used. The study used data on individuals from a longitudinal population-based investigation from the Butajira region combined with rainfall data from a local site. Additional routinely collected demographic, meteorological and agricultural data were used also. (Emmelin et al 2008)

Quoting from the report by Emmeling et al (2009): "*Rainfall was high in 1998 and well below average in 1999 and 2000. In 1998, heavy rains continued from April into October, in 1999 the small rains failed and the big rains lasted into the harvesting period. For the years 1998/1999, the mortality rate was 24.5 per 1,000 person-years, compared with 10.2 in the remainder of the period 1997/2001. Mortality peaks reflect epidemics of malaria and diarrhoeal disease. During these peaks, mortality was significantly higher among the poorer. A serious humanitarian crisis with the Butajira population occurred during 1998/1999, which met the USA-Centre for Disease Control (CDC) guideline crisis definition of more than one death per 10,000 per day*." (Emmelin et al 2008)

It can be concluded that in extreme droughts such as this one in Ethiopia in 1999/2000, the poorest in the farming communities are vulnerable to major heath effects as well as economic and social effects. Food insecurity and reliance on subsistence agriculture continue to be major issues in Ethiopia and similar communities. Also, under these circumstances, epidemics of traditional infectious diseases can still be devastating in mal-nourished populations with little access to health care. (Emmelin et al 2008)

5. Impacts

Besides substantial economic and social impacts, the health impacts of a severe famine due to drought (or other causes) are hard to measure. However, one survey conducted in 2000 in Gode district (southeastern Ethiopia and epicentre of the famine) of 595 households (4032 people), showed that mortality rate in children under 5 was 6.8/10,000 per day (95% CI 5.4 – 8.2/10,000), about double the crude mortality rate which was 3.2/10,000 per day (95% CI 2.4 – 3.8). The mortality rate was declining by the time intervention was introduced and then increased, however, 225 (76.8%) of all the deaths had occurred before any intervention had arrived. (Salama 2001)

The increase in mortality rate may have been due to influx of non-immune malnourished people to the centralised intervention centres. Almost 80% of all deaths were among children aged 14 years or younger and around 8% occurred among older persons. In addition wasting together with one of four major communicable diseases contributed to 206 (70.3%) deaths (communicable diseases included: measles, diarrhoea, malaria and respiratory tract infection). Cause of death was different before and after the intervention was started, excluding the other category, 29% vs 15% attributed to wasting alone before and after intervention respectively, 55% vs 50% attributed to wasting and one of the four major communicable diseases and 16% vs 35% to one of the four communicable diseases alone respectively ($p < 0.01$ for all). (Salama 2001)

In total, wasting alone contributed to 72.3% of all deaths among children under 5 years. The authors highlight the fact that there is no standard nutritional assessment tool for adults, and that in the study area, lack of data on adults resulted in groups potentially at high risk of mortality due to malnutrition not being targeted for feeding interventions. In addition, understanding adult nutritional status is important as it can contribute to a better understanding of community nutritional status. In addition, finding low prevalence rates of wasting in children in such situations could lead to an erroneous conclusion that nutritional situation is stable or improving because by the time nutritional assessments are done, those who are severely malnourished may have already died. But death is not always registered or recorded, notably; the authors remark that there was no available local baseline mortality data.

They suggest that collecting and analysing retrospective mortality data may be particularly important for the interpretation of results from nutrition surveys in prolonged famines. (Salama 2001)

But, famine is probably not equally spread in one population. It is generally assumed that, to the extent possible, adults will protect younger household members from the worst hunger. In Ethiopia, where girls have lower social status, it is possible that boys are more protected than girls. A study into this in southwestern Ethiopia indicates that boys and girls were equally likely to be living in severely food insecure households. But, girls were more likely than boys 9including their siblings) to report being food insecure themselves and more so in severely affected households. (Hadley et al 2007)

Droughts have occurred in many places other than Ethiopia and not necessarily always led to famines. However, it is relevant to investigate where substantial droughts have occurred and what impacts they had.

6. Comparable Other Events

Droughts can be due to many climactic events on of which can be the change in weather patterns during an ENSO (El Niño/La Niña-Southern Oscillation), a climate pattern that occurs across the tropical Pacific Ocean on average every five years) event alters regions of high and low pressures around the globe. They cause high surface pressures that prevent the areas of precipitation from moving into its region and lead to drought conditions, depriving the area and ecosystem of rainfall. Droughts generally occur in the western Pacific during ENSO Events, an area normally rich in rainfall. However, droughts in many other regions of the world, including south eastern Africa, India, China and north eastern region of the South American continent, have been linked to El Niño. ENSO results in drier conditions in Northeast Brazil during the Northern Hemisphere winter, the climatic impact of El Niño is drier conditions in Central America, Colombia and Venezuela.

During the 1997/1998 it caused severe droughts and forest fires in northeast Brazil. (World Meteorological Organisation 1999) The dry spells observed in the La Plata Basin, was studied using daily data supplied by 98 stations during variable periods between 1900 and1998. (Naumann et al 2008) From this it appears that the 1988 drought is considered to be the one of the longest dry spell in the basin. Water deficits translate to Argentinean economic losses of more than four billion dollars.

In 2005 large sections of south western Amazonia experience one of the most intense droughts of the last hundred years. (Marengo et al 2007) The through severely affected human population along the main channel of the Amazon River and its western and south western tributaries, the Solimões (also known as the Amazon River in the other Amazon countries) and the Madeira River, respectively. The river levels fell to historic low levels and navigation along these rivers had to be suspended. The causes of the drought were not related to El Niño but to: 1) the anomalously warm tropical North Atlantic, 2) the reduced intensity in the northeast trade wind moisture transport into southern Amazonia during the peck summertime season, and 3) the weakened upward motion over this section of Amazonia, resulting in reduced convective development and rainfall. The drought conditions were intensified during the dry season into September 2005 when humidity was lower than normal and air temperature were 3º - 5º warmer than normal. Because of the extended dry season in the region, forest fires affected part of south western Amazonia. Rains returned in October 2005 and generated flooding after February 2006.

The years 2008 and 2009 are considered to be one of the worst droughts in 50 years devastated crops, dry rivers and springs, and killed cattle in Argentina, a phenomenon also impacted on socio-economic and productive communities and regions. La Niña 2008-2009 depleted water reserves not only in Argentina but also in Paraguay, Uruguay and Brazil. According to the Meteorological Weather Service of Argentina (SMN), during 2008 observed rainfall values were below normal in most of the humid and semi-humid region of the country (the Pampas), comparing with the main value of the period 1961-1990. The accumulated rainfall in the center of the region represented only 40-60% of the normal values, and in some locations values of precipitation were the lowest of the last 47 years.[4]

[INSERT FOOTNOTE 4 HERE: Secretaría de Agricultura, Ganadería, Pesca y Alimentos. MECON. Argentina.]

It is unclear how much these severe droughts have affected the actual nutritional state of the populations affected or their long-term economic situation. However, Argentina is an important wheat producer and highly contributes to global exportations. The main planted area is located in the Pampas region, where the crop is developed under rainfed conditions. In the last decade, the area devoted to wheat ranged between 4.9 and 7.3 millions of hectares, mean yield attained 1,900-2,600 kg/ha, and country's production varied between 9.4 and 16 millions of tons (Mt). The internal consumption is near to 6 Mt, and remainder production is exported, transforming the country in the fifth world's exporter with a key role in food security. In Argentina the 2008-2009 draught impacted the richest agricultural area (Pampas region), substantially reduced grain production and caused millions US dollars in losses to livestock in the country.[5]

[INSERT FOOTNOTE 5 HERE: Secretaría de Agricultura, Ganadería, Pesca y Alimentos. MECON. Argentina.]

Drought is considered the major disaster occurring in the Arab region, where, the total people affected between the years 1970-2009, by drought is of about 38.09 million. (Abu Swaireh 2009) The Global Assessment Report included Mauritania, Sudan and Comoros Islands as countries exposed to drought hazard. Some countries of the region are also economically vulnerable to natural hazards and Syria could be considered one of the most economically affected countries by drought. (Global Assessment report 2009) The year 2008 is considered to be one of the worst droughts in devastated crops in Syria, The drought frequency increased during the last 10 years, and the rainfall as total and variability have shown negative impact on yield for most of the years. The rainfall was not enough to satisfy the water requirements of the cereal crops, beside half of the animal population in the steppe areas has been died or get read of due to the continues drought cycles. As a consequence of the agriculture drought the population immigration increased from the northwestern part of Syria and from Syrian steppe to Urban causing high pressure on the services and stability of those communities. (Erian 2010, Nashawatii 2010)

Mongolia is another country that regularly suffers drought and the country has experienced a drought every three years. Depending on drought and precipitation levels, the condition of the vegetation cover in the pasture lands differs from year to year. (MARCC 2010) Studies show that during drought years the vegetation cover diminished by 12-48% in high mountain areas and by 28-60% in the desert and steppe regions. (L.Natsagdorj 2002, L.Natsagdorj, et. al. 2003) Drought has increased significantly at the level of 95 per cent in Mongolia for the last 60 years, particularly in the last decade. The worst droughts Mongolia experienced were in the consecutive summers of 1999, 2000, 2001, and 2002, which affected 50-70 percent of the territory. Such long-lasting and severe droughts have not been observed in Mongolia in the last 60 years. However, besides the episodic drought, Mongolia suffers from systematic reductions in rainfall. During the past four years, about 3,000 water sources including 680 rivers and 760 lakes have dried up. Such environmental degradation in turn has affected the level of primary production of vegetations/plants and water resources, which support livestock as well as human populations. (AIACC, 2006) Because of the systemic nature, the drought in Mongolia was not regarded as a natural disaster, unlike in many African and South Asian countries. However, it has resulted in: a) the decrease of pasture plants; (b) the decrease of palatable species in pasture plant; (c) reduced water availability; and (d) the absence of grass on pasture. This prevents herders from preparing hay and other supplementary feed for animals and dairy products for themselves. Most importantly, animals are unable to build up the necessary strength (i.e., calories/fat) during the drought period in summer to enable them to cope with the harsh winter and spring windstorms and therefore, they die in large numbers resulting in economic and social hardship. (AIACC, 2006)

7. Policy-Management Practices – DRR / DRM / HFA / CCA – Response-Recovery

Considerable achievements in the global reduction of hunger and poverty have been made but, progress in Africa so far has been very limited. It is estimated that a third of the African population faces widespread hunger and chronic malnutrition and is exposed to a constant threat of acute food crisis and famine. Traditional rural households are most affected and are forced to adopt coping strategies to meet their immediate needs. This may have adverse long-term impacts on both the population and the environment. (Haile 2005)

In the absence of safety nets and appropriate financial support mechanisms, humanitarian aid is needed to allow people to cope with emergencies and manage their limited resources more efficiently. Timely and appropriate humanitarian aid will provide households with opportunities to engage in productive and sustainable livelihood strategies. For the longer term management, investments in poverty reduction efforts require timely and predictable response mechanisms in crisis situations. With an improved understanding of climate variability including El Niño, the implications of weather patterns for the food security and vulnerability of rural communities have become more predictable and can be monitored effectively. (Haile 2005)

The traditional approach to drought management has been reactive, relying largely on crisis management. This approach has been ineffective because response is untimely, poorly coordinated, and poorly targeted to drought stricken groups or areas. (Whihite 2005) Two important trends in drought management could be considered: (1) improved drought monitoring tools and early warning systems (EWSs) and (2) an increased emphasis on drought preparedness and mitigation. Effective drought EWSs are an integral part of efforts worldwide to improve drought preparedness. Activities of regional centers in eastern and southern Africa and efforts in WANA are increasing, but not enough. An Expert group meeting on EWSs sponsored by the World Meteorological Organisation and others summarized the shortcoming on the following areas:

- Lack of data networks on all major climate and water supply parameters
- Inadequate data sharing and high cost of data limits the application of data in drought preparedness, mitigation and response
- EWSs products are not user friendly; inadequate indices for detecting the early onset and end of drought
- No historical drought database exists. (Wihite 2000)

In India, Syria, and in the Arab Center for The Studies of Arid Zones and Dry Lands (ACSAD), major research efforts on improving the productivity of rainfed areas with focus on reducing the adverse effects of drought have been underway for at least 2-3 decades. These include improving and introducing appropriate crops, improved varieties and new varieties of cereal that are tolerant to drought and heat; improving conservation of soil and water increasing areas of conservation agriculture, improving water efficiency and improvement in terms of living conditions of the rural areas who suffer most due to scarcity and drought in particular.

In arid, semi-arid and marginal areas with a probability of drought incidence it is recommended to re-planning their land use and developing methods of predicting many weeks/months in advance, the occurrence of rainfall deserves high priority. The agricultural planning and practices need to be worked out with consideration of overall water requirement within the individual agro-climatic zones. Crops that need shorter duration to mature and require less water need to be encouraged in the drought prone areas. Food reserves to meet the emergency of maximum up to two consecutive droughts must be planned.

Africa is thought to be the part of the world that is most vulnerable to climate variability and change, but knowledge of how to use climate information and the regional impacts of climate variability and change in Africa is rudimentary. Besides predictions of rainfall, the entire food chain needs to be reconsidered, from production to distribution, access and utilization. Even complete changes in types of grains and cereals are to be evaluated. (Slingo et al 2005)

8. Drought Monitoring and Early Warning: Preparedness/ Response, National and Local Levels

Drought is typically a slow-onset phenomenon, which means that it is often possible to provide early warning of an emerging drought. Global Circulation Models (GCMs) and associated statistical ensemble methods are being routinely used to provide predictions of upcoming climate anomalies and offer promise for increasingly useful forecast of the onset, severity and duration of drought for large geographic regions on monthly and seasonal timescales.

There have been important developments[6] in recent years in the area of subseasonal and seasonal-to-interannual prediction, leading to dramatic improvements in predictions of weather and climate extremes (Nicholls, 2001). Some of these improvements, such as the use of soil moisture initialization for weather and (sub-)seasonal prediction (Koster et al., 2010), have potential for applications in transitional zones between wet and dry climates, and in particular in mid-latitudes (Koster et al., 2004). Such applications may be potentially relevant for projections of temperature extremes and droughts.

[INSERT FOOTNOTE 6 HERE: See S. Mason (IRI, Chapter 3) and Early Warning case study – 19 in this chapter.]

9. Relationship to Key Messages

- Droughts have historically occurred and led to severe famines and other effects
- Droughts are likely to occur more widely and frequently
- Areas where droughts currently do not result in famines, might do so in the future
- Other effects from drought (economic, social and other health effects) are likely but insufficiently investigated

10. Research Gaps

At this time, periods of drought are poorly assessed in their economic, social and health impact. Also, there is no clarity and worldwide agreement on potable and agricultural water supply needs of populations.

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Case Study 9.4. Sand and Dust Storms

Authors: W.F. Erian, Oyun Ravsal

1. Introduction – Asian Dust Cloud of 2001

A major dust storm started over East Asia on 6th April 2001 and dust from this storm was transported all the way to the United States. This "Asian Dust Cloud, 2001"[7] affected large areas of the world for the next two weeks Although dust from the Sahara Desert is routinely transported across the Atlantic to the east coast of the United States, Asian dust rarely makes the distance across the Pacific to the west coast of North America. These airborne microscopic dust and smoke particles, or aerosols, are measured by the Total Ozone Monitoring Spectrometer (TOMS) instrument on the Earth Probe satellite. For governments struggling to meet national air quality standards, knowing more about the sources and movement of pollution across national borders has become an important issue. Recent advances in satellite imagery allow the tracking and documentation of these huge Asian aerosol clouds. The dust cloud trajectory monitored from SEAWIFS had been observed day by day. In this case a thick shroud of dust appeared on April 6th, 2001 over Mongolia and formed a series of huge sandstorm events. These swept across western China reducing visibilities to near zero and making ground transportation all but impossible. The dust cloud trajectory monitored during the period from 7-11 April 2001 could be observed day by day by satellite and the cloud reached Arizona by 12th April with a dramatic and very distinct frontal boundary. Within hours, a thick veil of dust covered the entire sky. The haze layer was initially confined to layers aloft (April 12th and 13th) but by April 14th and 15th, as subsidence set in with a developing high pressure system, the main band of aerosols moved down to lower levels and the local visibility which is normally unlimited was reduced down to 30 miles or less. The trapped hazed layer persisted in Page, Arizona until the April 16th. The Asian Cloud at higher levels was eventually tracked into the Midwest region of the United States. After 11 days the dust storm from Mongolia that has dispersed dust from the Gobi Desert and industrial pollution from China across a quarter of the mainland United States seemed to be ended.

[INSERT FOOTNOTE 7 HERE: http://science.nasa.gov/science-news/science-at-nasa/2001]

2. Asian and African Sand and Dust Storms: Sources and Frequency

Sand and dust storms are natural events that occur widely around the world, especially in the dry lands which occupy half of the world's land surface. It has been estimated that in arid and semi-arid zones of the world, 24% of the cultivated land and 41% of the pasture land are affected by moderate to severe land degradation from wind erosion (Sivakumar, 2005). Dust storms are recognized as having a very wide range of environmental impacts. Atmospheric mineral-dust loading is one of the largest uncertainties in global climate-change modeling and is known to have an important impact on the radiation budget and atmospheric instability (Washington et al., 2003). The major sources of present-day dust emissions are the subtropical desert regions and the semi-arid and sub-humid regions, where dry exposed soil is subject to severe winds at certain times of the year. Human-induced change is by far the most significant factor in the alarming increase in some regions. Past policies on land use and the promotion of farming systems that were unsustainable are at the root of most of these changes (Sivakumar, 2005). Analysis of TOMS data has enabled a global picture of desert dust sources to be determined and it has demonstrated the primacy of the Sahara and has also highlighted the importance of some other parts of the world's drylands, including the Middle East, Taklamakan, southwest Asia, central Australia, the Etosha and Mkgadikgadi of southern Africa, the Salar de Uyuni in Bolivia, and the Great Basin in the United States (Washington et al., 2003). In the West Africa Sahel, rapid population growth, at annual rates of 3% during recent decades, has increased demand of food. Instead of intensifying farming systems, the previously sustainable fallow system has broken down, yield have declined, and more marginal land, which used to be communal grazing land, is now cropped. Consequently, over-exploitation has resulted in land degradation, or desertification, on a large scale. In his study to identify the sources of Asian dust, Zhang et al (2003) concluded that the deserts in Mongolia and in western and northern China (mainly the Tkimakan and Badain Juran, respectively) contribute 70% of the total dust emissions; non-Chinese sources account for 40% of this. Several areas, especially the Onqin Daga sandy land, Horqin sandy Land, and Mu Us Desert, have increased in dust emissions over the past 20 years, but efforts to reduce desertification in these areas have a little effect on Asian dust emission amount because these are not key sources. They added that meteorology and climate have had a greater influence on Asian dust emissions and associated Asian dust storm occurrences than desertification. The impacts of natural and anthropogenic factors on sand and dust storm distribution of 2001 in East Asia have been investigated by using the most up-to-date desertification map in China and desert reversal scenarios in natural precipitation zones, show that although desertification in China has only increased total area of desert by 2-7% since 1950s, it has generated disproportionably large areas with dust storm production potentials, depending on the degree of desertification newly formed deserts covered 15-19% of the original desert areas and would generate more dust storm ranging from 10-40% under the same meteorological conditions for spring 2001, Among the natural factors, the restoration of vegetation covers in Chinese deserts within the 200mm/y and 400mm/y precipitation zones was found to decrease the surface mass concentrations by 10-50% in most regions It was also found that the contributions of surface concentrations from non-Chinese deserts account for up to 60% in Northeast China and up to 50% in Korea and Japan (Gong et al., 2004).

Chun *et al* (2008) reviewed the documentation of Asian dust events, and concluded that the temporal distribution of dust storms in China during the period from 1915-2005 shows two peaks: during the warm perido of the 1930's and again in the last few years. Guoguang (2002) indicated that the main tracks of dust storms in China have three paths: North-Westerlies, Westerlies and Northerlies. The long-term variation of annual accumulated days of dust weather in China shows high frequency period: 50's-70's in cold and dry seasons with frequent development of extra-tropical cyclones and cold waves, with , decreasing frequency period: 1982-1997 and recent increase since 1998 that characterized with dry climate condition, increasing dry soil and warmer temperature layer thicker than 3 cm. Natsagdorj *et al* (2003), based on their observation for the compiled climatologically data of dust storms in Mongolia collected from 49 meteorological stations from 1960 to 1999 and compared with data between 1937 and 1989. An important outcome of this study is the trend of dusty days between 1960 and 1999. It shows that the number of dusty days has tripled from the 1960s to 1990s and has decreased since 1990.

The Sahara is the largest source of desert dust, indicating the importance of aeolian geomorphology in this major world desert (Middleton and Goudie 2001). Dust storms moving from the Sahara desert to the Eastern Mediterranean sea basin can occur between October and May, but mostly from December to April, (Dayan et al., 1991). A March 2003 event strongly resembled a February 1903 dust fall episode that was well documented in the contemporary literature, 100 years ago. The 1903 February 21-22 dust event impacted northern Europe including southern England, northern France, Holland, Germany and Denmark. For the early researchers, the most conclusive evidence regarding the Sahara origin of the dust was derived from the meteorological sources. Using the measured pressure fields they were able to map the trajectory of several dust bearing storms and traced them back to a point of origin in northern Africa. The source regions of dust particles that found on the south-Eastern corner of Italy during Saharan dust storm events have proven to be from the central and western Sahara, the samples collected along dust events with the origin mainly in Chad, Niger, Algeria and Libya, (Blanco et al., 2003). A recent Sahara dust incursion to northern Europe recorded by the Sea-Viewing Wide field-of-View Sensor (SeaWiFS) satellite on March 15, 2003. A thick yellow dust cloud is seen over England and France. Operational forecast models show that the dust source was over North Africa. This dust transport event, like many other recent dust events, has attracted a great deal of admiration particularly due to the real–time availability of spectacular color satellite images. However, just like most other dust events, it was not analyzed quantitatively for its key physical and chemical features (Husar, 2004).

3. Impacts of Sand and Dust Storms

Sand and dust storms, especially major ones, can be hazardous extreme events with major impacts. These impacts can be negative and positive.

3.1. Negative impacts

When sand and dust storms occur, they act almost like an overwhelming tide and the strong winds carry drifting sands that can: bury farmlands and blow away top soil; denude steppes; hurt animals and damage young crop plants and result in a loss of production; and reduce the temperature and pollute the atmosphere. Sand and dust storms accelerate the process of land desertification and cause serious environment pollution and huge destruction to ecology and living environment. They also effect human settlements through, for example, destroying mining, and communication facilities, and impacting on human health through the inhalation of dust and increasing the spread of disease across the globe. Virus spores in the ground are blown into the atmosphere by the storms with the minute particles which then act like urban smog or acid rain. Other hazardous consequences include severe threats to the safety of transportation (reduced visibility affecting aircraft and road transportation) and electricity supplies and they contribute unforeseen impacts to people's life and property (Wang Sh., et al., 2001).

The large amount of dust that is transported from the desert in China to Korea and Japan often provide long-range transport to various microorganisms, including Aquabacterium sp., Flavobacteriales bacterium sp., Prevollaceae bacterium sp.,and others. The result is that humans in the affected regions are exposed to communities microorganisms that might cause various adverse health effects (Lee et al., 2009). Sand storms may be a potential source of exposure to Polychlorinated biphenyl (PCBs). The total PCB residues analyzed from samples taken from the yellow dust storms indicated that its concentration ranged from 1.6 to 15.6 ng g^{-1} with tri-chlorinated biphenyls as the predominant homologue (>50.4%)(Fu et al , 2008).

In his study on health impacts caused by dust days in the Dair El Zohr area in Syria, Al Ebaid (2000) indicated that dust days cause breathing problems that impact on 60% of the total population mainly in rural areas; 70% of the population suffers eye diseases and 25% suffers digestion problems with emergency cases increasing by 380%. Toxicity of coarse particles is substantially less than that of fine particles. The microbial materials adhered to Asian sand/dust cause allergic lung inflammation. In Taiwan, Bell et al (2007) concluded that risk of hospital admission in Taipei may be increased by air pollution and sandstorms. Li-Wei and Wan-Li (2008) indicated that short-duration Asian dust storm events caused a larger revised air quality index (RAQI) than the long duration, PM_{10} and O_3 concentrations significantly increased on the first two days of the event. Yong-Shing et al (2004) concluded that the dust storms increased the risk for respiratory disease by more than 66% one day after the event, by about 5% for total deaths 2 days following the dust storms and by about 3% for circulatory diseases 2 days following the dust storms.

3.2. Positive impacts

Mineral dust, as has been suggested, has an important role to play in the supply of nutrients and micro-nutrients to the oceans and to terrestrial ecosystems (Shinn et al., 2000; Sivakumar 2005). Mineral dust is a term used to indicate atmospheric aerosols originated from the suspension of minerals constituting the soil, being composed of various oxides and carbonates. Human activities lead to 30% of the dust load in the atmosphere. The Sahara is the major source of mineral dust, which subsequently spreads across the Mediterranean and Caribbean seas into northern South America, Central America, North America, and Europe. Additionally, it plays a significant role in the nutrient inflow to the Amazon rainforest (Koren et al., 2006). The soil of the Amazon tropical rainforest is shallow, poor in nutrients and almost without soluble minerals. Heavy rains have washed away the nutrients in the soil obtained from weathered rocks. The rainforest has a short nutrient cycle, and due to the heavy washout, a stable supply of minerals is required to keep the delicate nutrient balance (Vitousek and Stanford, 1986). About 40 million tons of dust are transported annually from the Sahara to the Amazon basin, Saharan dust has been proposed to be the main mineral source that fertilizes the Amazon basin, generating a dependence of the health and productivity of the rain forest on dust supply from the Sahara, about half of the annual dust supply to the Amazon basin is emitted from a single source: the Bodélé depression located northeast of Lake Chad, approximately 0.5% of the size of the Amazon or 0.2% of the Sahara. Placed in a narrow path between two mountain chains that direct and accelerate the surface winds over the depression, the Bodélé emits dust on 40% of the winter days, averaging more than 0.7 million tons of dust per day (Koren et al., 2006). Central and South American rain forests get most of their mineral nutrients from the Sahara; Traces of African dust have been discovered as far west as New Mexico. According to Swap (1992), the western states are also the recipients of dust that's been stirred up in China's deserts and blown across the Pacific; the area of dust cloud observed was 1.34 million Km^2, the mean particle radius of the dust was 1.44 mm, and the mean optical depth at 11mm was 0.79. The mean burden of dust was approximately 4.8 tons/Km^2 and main portion of the dust storm on April 07, 2001 contained 6.5 million tons of dust, (Yingxin et al, 2003).

4. Measures for Adaptation to Sand and Dust Storms

The use of remote sensing technology, leading to improved and affordable, effective and efficient monitoring systems can enhance detection and modeling of sand and dust storms. They can also be used an important step for combating wind erosion (Husar, 2004; El-Askary et al., 2003; Koren and Kaufman, 2004). Preventing the sand from being picked up in the source area is the main cheaper and more effective action than to fixing the dunes formed in the accumulation area (Sivakumar 2005). Through use of live windbreaks, wind speeds could be reduced by 50% at a leeward distance of 20 times the barrier height (Skidmore, 1986). Planting and maintaining shelterbelts is an important conservation practice in the great plains region and it produce many benefits for farmers such as decreased soil erosion, increased crop yields, reduced livestock stress (Forman and Baudry 1984; Loucks 1984; USDA 1989). Protecting the loose soil particles by using crop residues or plastic sheets or chemical adhesives (Michels et al., 1995) and increasing the cohesion of soil particles by soil mulching are other possible approaches. These need to be further investigated. It needs also to be remembered that dust and sand storms do have positive attributes, as discussed, and these benefits need to be accounted for the analysis of adaptation strategies.

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Case Study 9.5. Floods

Authors: Sergey Borsch, Rosa Perez, Tae Sung Cheong, Soojeong Myeong, Virginia Murray and Harriet Caldin

1. Introduction

A flood is a ‘rise, generally brief, in the water levels in a stream to a peak from which the water level receded at a slower rate’ (United Nations Educational, Scientific and Cultural Organization/World Meteorological Organization, 1992). There is a common basis between floods is related to heavy (or long) rainfall and air temperature, which can lead to *water logging of the soil, river floods (or flash floods) and landslides*. Some floods overflow the normal confines of a stream or other body of water and cause flooding over areas which are not normally submerged (World Meteorological Organization, 2010). Floods cause not only material damage, but lead to loss of life and have adverse effects on the health of people.

Floods have been a major natural hazard in many regions of the world. There have been several recent flood events, in each of which the material losses are reported to have exceeded US$ 10 billion (material damage during the summer 1998 floods in China rose to US$ 30 billion) (Kundzewicz 2006). The death toll has remained high, with single events in less developed countries causing more than 1,000 fatalities (Kundzewicz 2006). Floods occur because of complex interactions between hydro meteorological and hydro-geological processes, usually classified according by rain, sea or snow floods, flash floods, storm surge, mudflow, and ice jams (Collins 2007).

2. Catastrophic Floods in Mozambique in 2000

2.1. Hydrometeorological and geographical background of floods in Mozambique

Mozambique is vulnerable to natural disasters such as tropical cyclones, floods and droughts because of its geographical position. From 1956 to 2008 Mozambique experienced 20 major floods (killing 1,921 people), 10 major droughts (killing 100,000 people) and 13 major tropical cyclones (killing 697 people) (World Bank 2005). Mozambique’s high incidence of flooding is explained by two influential factors. Firstly the meteorological factors, especially the tropical cyclones that form in the southwestern Indian Ocean and sweep towards the country’s coast. While relatively few of these actually make landfall, an average of three or four get close enough each year to cause high winds and heavy rain, leading to flooding. Further variations in rainfall are strongly related to sea surface temperature variations in the Indian Ocean and the Atlantic which may sometimes alter normal tidal patterns.

The second factor is the geography. Mozambique is a ‘downstream’ country. Nine out of the eleven rivers in Mozambique are trans-boundary rivers. Mozambique is the last riparian country before the rivers discharge into the Indian Ocean. As a result, the quantity and quality of the water resources available to the country is dependent on activities of the upstream countries, the water which caused the most damaging floods originated upstream from other riparian countries: South Africa, Botswana and Zimbabwe. The management of water flows from two major dams, the Cabora Bassa and the Kariba, also has a major impact on flood risks in Mozambique. Early warning and flood control systems for Mozambique are therefore an international issue that involves close collaboration with other countries of the Southern Africa Development Community (SADC). The importance of adapting disaster risk management (DRM) to new climate change situations becomes very apparent when conflicting weather fronts clash, and flooding crosses international boundaries.

Every continent can suffer from devastating floods when rivers run through several countries. In August 2002 a 100-year flood caused by over a week of continuous heavy rains ravaged Europe, killing dozens, dispossessing thousands, and causing huge damage in the Czech Republic, Austria, Germany, Slovakia, Poland, Hungary, Romania and Croatia.

2.2. Event summary of floods 2000 in Mozambique

In January-February of 2000, the Mozambican coast was hit by a series of tropical storms. According to a report of the United Nations Office for the Coordination of Humanitarian Affairs (UNEP/UNCHS 2010) in late January 2000, torrential rainfall caused the flooding of the Incomati, Umbeluzi, and Limpopo rivers in Maputo and Gaza Provinces of Mozambique. Following this, from 4 to 7 February, Mozambique then received the heaviest rains in 50 years. The accumulated rainfall over a three-day period in Maputo Province alone reached 455mm compared to a total rainfall of 549 mm from September 1998 to 31 January 1999.

The extreme rainfall was concentrated in two periods, from 5th to 10th February and from 22nd to 25th February 2000, and was caused by tropical weather systems that moved from west to east over the subcontinent (Dyson 2000). The combination of the two systems and high levels of soil saturation from an already wet December resulted in excessive flooding (Van Biljon 2000).

The most severe of the tropical weather systems was cyclone Eline, which followed cyclone Connie (Kwabena at al. 2007). Eline made landfall on February 22nd, moving over the headwater basins of the Limpopo River and causing record amounts of rainfall. The historically high rainfall from Eline, coupled with saturated soil conditions due to the passage of Connie, produced a flood wave in the lower regions of the Limpopo basin.

From 21 to 22 February cyclone Eline hit the Inhambane and Sofala Province, and a month later banks burst in Gabo Delgado, North Western Tete Province as flood crests moved down the Zambezi, Save and Buzi Rivers.. Waves of water, reaching up to three meters high, descended down the river and flooded the whole city of Chokué and the commercial area of Xai-Xai City both in Gaza Province. The Save River was also flooded by water from Zimbabwe. Further south the towns of Vilanculo and Inhassoro in central Inhambane province were cut off due to flooded roads.

The torrential rain also washed away roads in the north of the country which had not been affected and flooded four villages. These floods destroyed the main road, which runs from the north to the southern part of the country 110 kilometres from the Tanzanian border (UN General Assembly 2000).

2.3. Impacts of floods 2000 on the population and economy of Mozambique

Heavy floods in February and March 2000 had both devastating direct and indirect impacts on the population and economy of Mozambique. The emergency hit a country which is among the 10 poorest of the world, with a poverty index of 70 per cent. It affected 12.1 per cent of the population, that is, 2.04 million people in five provinces; more than 700,000 of them required assistance. Among these, 500,000 were displaced by the floods and temporarily sheltered in over 100 camps set up by the Government. 699 lives were lost. The impact of the floods on all sectors of the economy was enormous: 10 per cent of the cultivated land was destroyed, while 90 per cent of the irrigation structure in the affected areas was damaged. More than 600 primary schools were either destroyed or severely damaged, as were health posts and hospitals. The World Bank estimates that direct losses amount to US $273 million, while lost production amounts to $247 million (UN General Assembly 2000). The principle water system in the capital Maputo was destroyed cutting off the water supply.

Japan Disaster Relief was sent to provide health care to flood-disaster victims for nine days between 16th and 29th March to the Hokwe area of the State of Gaza, in the mid south of Mozambique, where damage was the greatest (Kondo et al 2002). Besides providing care to 2,611 people they conducted an epidemiological study. Infectious diseases were detected in 85% of all of patients, predominantly malaria, respiratory infectious diseases, and diarrhea. Of note they reported the incidence of malaria (28%) with 43% of cases being identified in children aged 1-4. They speculated that malaria had increased by four to five times over non-disaster periods with both the incidence and the risk of infection augmented following the flood. It was reasoned that this increase in infectious disease incidence was due to the heightening of the associated risk factors:

- Increase in population density
- Temporary living conditions
- Degeneration of quality of drinking water

- Physical strength deterioration due to lack of food.

The findings support the hypothesis that in the aftermath of a flood transmission of waterborne disease increases and there are heightened levels of endemic illness.

2.4. Role of key personnel and agencies

In 1999, a new national Government policy on disaster management was formed that created the National Institute for Disaster Management (INGC) with an emphasis on coordination rather than delivery (World Bank 2005). This reflected a shift in aid given by both national and international agencies from emergency response to development following the end of the civil war in 1992. From September 1999, INGC, the National Meteorological Institute (NMI) and the Southern African Regional Climate Outlook Forum (SARCOF) began to warn of weather forecasts indicating an unusually heavy rainy season. In the September-December period, there were a number of front-page articles in the local press repeating that warning. In November 1999, the Minister for Foreign Affairs and Cooperation, accompanied by the United Nations Resident Coordinator held a meeting for the press and the international community to launch the INGC contingency plan for 1999-2000

The Ministry of Health instructed its provincial directorates to prepare for possible floods, illustrating that the protocol was followed in advance; practicing the now known wisdom that DRM is facilitated by anticipatory strategies within and between sectors. Contingency stocks of medicines and implementation plans for staff response were developed (UN General Assembly 2000) indicating the process off filtering top-down knowledge to local management levels and some of the general considerations laid out in the Hyogo Framework for Action (HFA) such as:

- The involvement of international cooperation
- An integrated multi-hazard approach to Disaster Risk Reduction (DRR) in all policies is advisable
- Communities and local authorities need to be empowered, the relationship between international and regional agencies needs to be one of cooperation
- Proactive measures need to be taken in order to have an effective programme for Climate Change Adaptation (CCA).

Most people in the affected areas received warnings issued by the water management about the rising river levels in upstream reaches of the Limpopo River and warned people in low-lying areas to move to higher ground. However, the warnings were qualitative in nature, and they failed to convey the magnitude of the event (Kwabena et al. 2007). This scenario has great implications for communication systems and their role in facilitating CCA, as it is through good communication that international and local cooperation occurs, that knowledge transfer and innovation can enhance early warning and cause actions to occur once the warning has been given. Poor communication flow can impede the awareness of risk determinants diminishing the ability to adapt to climate change.

There were problems with the installation and maintenance of in situ gauging equipment due to financial constraints. This is an illustration of a DRM culture that did not embrace prevention and where there was a lack of resources and anticipation, key factors for CCA. In addition, in situ flow and precipitation gauges are often washed away by the very floods they are designed to monitor, and reconstruction of gauges is a common post-flood activity around the world (Asante et al. 2005). By the time the third and largest flood wave arrived, many key stations were already destroyed, leaving Mozambican water authorities with no source of information on the actual magnitude of floodwater. They consequently relied on their knowledge of previous flood events to issue the flood warnings. The 2000 floods turned out to be far more severe than any previous event in living memory, and many areas previously regarded as safe were inundated (Kwabena et al. 2007). The failure of the scientific Early Warning Systems (EWS) led to a reliance on local knowledge, showing how local knowledge needs to be valued and absorbed into DRM policy, but also how this also needs to interplay with reliable scientific tools, as climate change is causing unpredictable magnitudes of effect.

At the request of the Government and the Resident Coordinator, the Office for the Coordination of Humanitarian Affairs fielded a United Nations Disaster Assessment and Coordination (UNDAC) team immediately in response to the 12th February floods. Good international response was tantamount to the response effort, which is part of the HFA, as would have been expected from Mozambique's historical use of aid. The coordination between civil international staff and military personnel from seven countries became a particularly important task of the UNDAC teams, their services during the acute phase of the emergency were invaluable: overall, some 50,000 people were rescued (UN General Assembly 2000).

In February, the Government of Mozambique and the United Nations entities appealed for some $60 million for 300,000 flood victims. The impact of Cyclone Eline drastically increased those requirements, and $130 million was contributed by donors to the relief phase. On 22nd March, the Government and United Nations entities launched a transitional appeal, seeking $100 million of additional emergency assistance for the benefit of more than 600,000 flood victims until the next agricultural season in September. A massive national and international relief operation avoided greater loss of life with 16,500 people rescued by helicopter and aircraft, and over 29,000 rescued by boats (World Bank 2005).

The International Conference on the Reconstruction of Mozambique, organized by UNDP with the Government of Mozambique in Rome on 3rd and 4th May 2000, succeeded in obtaining pledges of $453 million for the reconstruction (UN General Assembly 2000). This conference was the reaction of the international community to the catastrophic flooding having a place in Mozambique in the beginning of 2000.Clearly there was very good cooperation between national structures and international aid although it is not clearly reported whether the reconstruction was planned in accordance to the HFA priorities and with climate change adaptation in mind. Particularly of concern is the issue of empowering local authorities and communities and taking a proactive stance.

Prior to the floods in 2000 Mozambique received a constantly high level of international aid and has a high dependency on foreign financial and developmental assistance. It must be recognized that a significant aspect of the response and recovery after the floods was the positive relationship with donors, hence the quick call for international help.

2.5. Lessons and problems

The enormous material damage and human losses during the floods in Mozambique in 2000 were associated with the following problems:

a) Institutional problems. In 1999 National Policy on Disaster Management in Mozambique marked a shift from a reactive to a proactive approach to disaster management aimed at developing a culture of prevention (World Bank 2005). Previously the national policy was mainly concentrated on disaster response and preparedness as opposed to prevention and mitigation. This illustrates a shift in thinking to accommodate climate change adaptation, so taking the standpoint that extreme weather events will occur, which are not preventable, therefore the response and process of disaster reduction should be the focus. The INGC's role in post-disaster recovery was linked to the mobilizing of resources and ensuring efficient transition between the relief and recovery phases and keeping the ministerial level Coordinating Council for Disaster Management (CCGC) informed of recovery activities. National Policy on Disaster Management did not have the legal backing of a national disaster management plan, although a draft plan was in the pipeline. Prior to the 2000 floods many agencies had allowed their strategy and planning documents for disaster response to lapse. The floods resulted in an updating of their strategy documents and a renewed commitment to disaster preparedness, response, and mitigation. However, there was little specific coverage in these policies for recovery strategies (World Bank 2005**).** The National Policy on Disaster Management covered the national level, but had not been sufficiently developed at the regional and local level. Training of the population and local authorities to act in emergency situations was insufficient.

b) Technological problems. Before the floods of 2000 active observational hydrometeorological measurement in Mozambique had been rare. Hydrometric measuring instruments and equipment were insufficient and largely outdated, so there was no provision of contingency systems. There was no protection of instruments and equipment from possible damage, and no plan for the timely replacement of equipment and devices. There were no reliable methods for quantitative forecasting of the hydrograph for the river of Mozambique. To ensure the secure, reliable and timely hydrological information during the start and development of flood requires close cooperation with all countries situated within transboundary river basins.

c) Financial problems. Insufficient budgetary resources singled out for the creation, development and maintenance of the National Policy on Disaster Management.

d) *International involvement Systems*. Recovery response was slow and delayed from many donor organizations. There was enormous international input into the recovery and future development process, which shows the value of international cooperation, the sharing of knowledge, financial assistance and support to the government. However the bureaucracy each donor organization had to manoeuvre within combined with the national government systems meant there was slow progress and little coordination. The World Bank, through building in a disaster policy into their funding, managed to fast track the flow of resources, but more external agencies need to put into place similar systems. In the Republic of Korea there is an economic and damage threshold that triggers the release of government aid after a disaster and after Typhoon Maemi a service was developed that allowed a rapid transfer of money to individuals from a recovery fund within 20 days, instead of the usual 90 days.

There was a sense from the community survey conducted by ANSA (Food Security and Nutrition Association – Mozambique) in October/November 2002 (World Bank 2005) that there was little local and regional involvement in programme design and development. Further standard ministry drawings and specifications were used to reconstruct schools and health care facilities. This raises the question of whether reconstruction was considered in terms of CCA and resilience.

2.6. Actions after the floods 2000

International and local coordination

A further limitation highlighted has been the use of international contractors rather than local ones for the reconstruction programmes. However, the ANSA survey did report that in some areas coordination between local authorities and external agencies was good and effective, however this was completely dependent upon the ethos of the individual foreign aid and not in the power of the local authorities.

Further, the report raised the concern that beneficiaries of the recovery aid were very poorly informed about the work and the plans, leading to disempowerment and a lack of ownership by the communities, which resulted in a greater dependency on external agencies. This will build weak local resilience to prevention, response and recovery for future flooding events. The participation that the community had was generally at the level of providing labour and compliance with externally set rules.

There was also a lack of communication and transparency between NGOs and government organizations about planning and finance (World Bank 2005).

After the floods of 2000 and 2001 the Government of Mozambique wanted to move quickly from activities of relief to those of recovery, seeing an opportunity for development, both in terms of improving infrastructure as well as reducing risk and vulnerability. Anticipatory strategies facilitates disaster risk management, and understanding the driving factors of vulnerability will enhance the effectiveness of these strategies, and lead to a better understanding of CCA.

Mozambique's government learned some tough lessons from the devastating floods that hit the country a decade ago. The disaster management plans developed by the government of Mozambique after the floods 2000 may be used as a model for other African countries.

In 2001, the government of Mozambique adopted an Action Plan for the Reduction of Absolute Poverty (PARPA I), which was revised for the period 2006–2009 (PARPA II). Drawn up with the assistance of the World Bank and international donors, it is intended to outline 'the strategic vision for reducing poverty, the main objectives, and the key actions to be implemented, all of which will guide the preparation of the Government's medium-term and annual budgets, programs, and policies' (Foley 2007, The National Action Plan 2001, republic of Mozambique Action Plan 2006). The first version did not give disaster preparedness prominence, only including a short section at the back which made reference to strengthened capacity and improved EWS, but there were no specific indicators or budget allocations. The second version illustrates a greater understanding of the link between poverty, development and disaster risk management. In October 2006, the government adopted a Master Plan, which provides a comprehensive strategy for dealing with Mozambique's vulnerability to natural disasters, covering issues ranging from the need for re-forestation and the development of a national irrigation system to the development of crops that can survive prolonged droughts.

After the floods 2000 Mozambique implemented intensive programs to move people to safe areas. Thus over the past five years about 120,000 families have been resettled.

One of the positive aspects of the recovery was the start of recognition for women. External agencies facilitated their greater involvement in community meetings and reallocated land and housing were registered to acknowledge women's rights. The HFA explicitly lists in its general considerations that a gender perspective must be part of DRM and this may also mitigate some of the social risk factors associated with climate change and disasters.

The infrastructure recovery work was extensive, rebuilding damaged and destroyed parts, usually to a higher standard, and the funding also allowed for the construction of new ones where there were none before.

The 2000 floods demonstrated that extensive recovery activities are possible after a disaster, and unlike many damaging events, the funding for the recovery was pledged and delivered over two years, allowing for a strong recovery period rather than all the funds being used on the relief period.

The country has put in place early warning systems some of which are operated by community members. An example of this is the Búzi Early Warning System (further description below).

For the development of modern preparedness strategies and early warning systems on the international level the South African Weather Service has developed a proposal to set up a regional flash flood warning system that would cover all affected countries within the region which Mozambique will be part of.

Mozambique has developed a strong collaboration between the meteorological services, hydrological services and disaster management teams. The flooding in 2000 killed 700 people. Since then, the government has increased the budgetary allocation for disaster management, put in place early warning systems, and established community-driven rescue systems. When heavy flooding occurred again in the 2007-2008 rainy season, an enhanced level of preparedness is credited with reducing the number of people affected.

Limitations

The ANSA survey found that post-emergency capacity building and training was minimal. Very few organizations worked with communities to identify existing skills, or create opportunities to reestablish and further income sources. There was no mention of work to prepare for the occurrence of further disasters, or to train local communities in appropriate response, as the HFA suggests. The high level recovery plans did include improvements to disaster response, however by 2005 this still had not filtered down to the district or local level, where there was little planning and preparedness, losing the opportunity to build on the positive experiences and respond to any lessons learned or experience gained during the floods. This reinforced the report from the World Bank that there was a gap in the procedures between rapid relief response and long term development.

The overall donor support to Mozambique after the floods was very good; however it was very unevenly distributed across the sectors. The productive and infrastructure sectors were well endorsed (123 and 213 US$ million respectively) however health, social welfare and education were poorly allocated to (90.3 US $ million combined). Factors associated with emergency response such as preparedness, early warning systems, capacity building and vulnerability reduction were the least well funded supported by only 21.9 US$ million (World Bank 2005). This illustrates the need for financial planning to support and lead on DRM by following the Priorities for Action as laid out in the HFA, and that CCA needs to actively invested in.

3. Floods in Mozambique in 2007

3.1. Event summary of floods 2007 in Mozambique

Between December 2006 and February 2007, strong rains across northern and the central Mozambique together with a serious downpour in neighbouring countries, have led to flooding in the Zambezi River basin in Tete, Manica, Sofala and Zambezia provinces. The World Meteorological Organization reported it to be the worst case of flooding since 2000 (WMO Reports 2007).

The 2007 Mozambican floods began in late December 2006 when the Cahora Bassa Dam overflowed from heavy rains on Southern Africa. The dam was discharging water at a rate of 7,000 m^3/s from 7 February 2007. The National Water Directorate increased the discharge rate to 8,400m $^3/s$, on 9 February, while the inflow into the dam reservoir has increased to 10,000 m^3/s. Due to the continuing heavy rains in Mozambique and neighbouring countries as well as the increased discharge rate at the Cabora Bassa Dam significant flooding was expected in the Zambezi River basin. The hydrological situation was worsened in February 2007 when the Zambezi River broke its banks, flooding the surrounding areas in Mozambique (DREF Bulletin 2007).

Additional flooding has been linked with the approach of tropical cyclone Favio (category 4) which struck the Búzi area on the evening of 22 February 2007. Tropical Cyclone Favio made landfall in Vilankulo District, Inhambane Province and continued through Sofala and Manica provinces. Strong winds and heavy rain caused major damage.

3.2. Impacts of floods 2007 on the population and economy of Mozambique

On 22 February 2007, when cyclone Favio hit southern coast of Mozambique, nine people were killed, 70 people were injured. The heavy rains, strong winds and floods damaged 17 health centres and an estimated 332 classrooms and 38 public administration buildings. It also destroyed drug stocks and medical equipment and affected safe water and sanitation facilities.(UN JCHA 2007). In total, the floods and cyclone caused approximately $71 million in damage to local infrastructure and destroyed 277,000 hectares of crops primarily in Vilanculos, Inhassoro, Govuro, and Masinga districts in Inhambane Province, according to the INGC (U.S. Agency for International Development Bureau for Democracy 2007).

The total number of people affected during the floods in January-February 2007 in Mozambique is estimated to have been between 300,000 and 500,000. The Department for International Development (UK) stated that 163,000 people had been forced to leave their homes due to the flooding, and that an additional 134,000 had been affected by Cyclone Favio (UK Department for International Development 2007) The World Food Program (WFP) states that the floods affected 285,000 people, and the cyclone 150,000 more (WFP Mozambique, 2007). It also reported that 140,000 flood-affected people had been placed in temporary accommodation centres in the Zambezi region, and that an additional 55,500 had moved to expanded resettlement sites established after previous floods. Tens of thousands of people lost their crops less than a month before the harvest, and essential infrastructure, including schools and hospitals, was badly damaged. USAID estimated that 331,500 people had been affected by the flood and 162,770 by the cyclone (USAID Mozambique 2007).

3.3. Role of key personnel and agencies

Activities of local authorities and agencies before and during the floods period in 2007

In 2005-2006 the German Agency for Technical Cooperation (GTZ) developed a simple but effective early-warning system along the River Buzi (Loster et al. 2007). This warning system was adapted to the specific needs and skills of the people. The village officials receive daily precipitation at strategic points along the Buzi river basin. At the same time, they monitor a water level with using of clearly marked gauges on the river. If precipitation is particularly heavy or the river reaches critical levels, this information is passed on by radio. If reports reaching the control centre indicate widespread heavy rainfall, the alarm is raised. Blue, yellow or red flags are raised depending on the flood-alert level and an army of helpers spreads the warning by megaphone. Critical areas are evacuated. This is a good example of a scientific high technology adaptation for DRM that has been tailored to the local community and capability.

During the course of January 2007, it became clear that there was an imminent threat of severe flooding in the Zambezi River basin valley. On 20 January the INGC, which had been monitoring the situation, began to call daily coordination meetings to plan its response:

- **On 26 January**, OCHA issued a regional flood warning which covered Zambia, Malawi and Mozambique.
- **On 30 January**, the INGC deputy director briefed the UN Country Team on preparations for potential flooding.
- **On 4 February 2007**, the INGC issued a formal ‘Red Alert’ warning that large-scale flooding was anticipated along the Zambezi River basin. The following day the INGC briefed the government’s Council of Ministers.
- **On 6 February**, the INGC wrote to WFP requesting support to respond to additional flooding needs.
- **On 7 February** Mozambique’s prime minister visited the Zambezi River valley and reported that incountry protocols, actors and resources were being effectively mobilised. She stated that the government, in cooperation with its in-country partners, including the UN, would be able to respond adequately to the flooding. She ordered the army to forcibly evacuate any people who had continued to defy instructions to leave the affected area.
- **On 8 February**, the UN Country Team decided to approach the other internal humanitarian actors to form an ad hoc Humanitarian Country Team. It was also decided to make a Central Emergency Response Fund (CERF) application for the expected floods, and to adopt the ‘Cluster Approach’ in its humanitarian response. The team asked for assistance from OCHA in Geneva to establish the necessary systems, and an official was immediately dispatched from its Humanitarian Reform Support.
- Active response steps taken: a) enforced evacuation b) resource management in response to warnings and c) international bodies called upon.
- **On 20 February** the district government received a blue-alert storm warning (cyclone approaching within the next 48 hours) advising that severe Tropical Cyclone Favio is on its way. The assessment and prognosis group of the SIDPABB (Inter District Operational Flood Warning System for the Buzi River Basin) is asked to monitor rainfall and water levels along the rivers.
- **On 21 February** the district government received a yellow-alert storm warning from the provincial government, indicating that Favio will arrive in 12 hours. The CENCOE (Disaster Operation centre) district office is advised and accordingly working groups are formed. Using two way radios and the local community and the services of the local council, the heads of the administrative centres and members of the local disaster-prevention committees are instructed to raise the warning flags and alert people to the approach of Cyclone Favio. The local disaster committees of Muchenesa, Inharague, Munamicua, Grudja, Begaja, Inhanjou, Estaquinha and Mamunje raised the warning flags. Following the instructions that are issued, people begin to leave the danger zones and make their way towards previously identified safer zones by their own means.
- **On 22 February** the Buzi district government received a red-alert storm warning from the provincial government.
- Active response steps taken: a) response to working EWS b) use of top down management approach that utilizes local resources and c) respect for warnings followed by appropriate action, unlike in 2000.

- **On 24 February** rainfall on the upper reaches of the River Buzi basin increased in intensity and the water level suddenly raised, exceeded flood-alert levels. The Buzi district government ordered the mandatory evacuation of the populations of five areas of Buzi. Regional Red Cross helpers worked in the local disaster-prevention committees.
- **On 25 February** lower-lying, flood-prone zones in the Buzi district, including parts of the district capital, were completely awash. All access roads to Buzi itself were cut off. On the assessment of Sergio Sional Moiane, head of the district government responsible for the Buzi: "The losses are dramatic but, without the disaster prevention programme, things could have been much worse"(Loster et al. 2007).

Activities of international organizations and humanitarian agencies

As a result of the flooding and cyclone, humanitarian agencies are concerned about the potential for outbreaks of water- and vector-borne diseases, such as malaria, cholera, and acute diarrhea. The U.N. Children's Fund (UNICEF) and the International Federation of Red Cross and Red Crescent Societies (IFRC) raised public awareness through health campaigns that included radio messages, community theatre performances, and promotional material on good hygiene practices. To address the increased risk of vector-borne diseases USAID/OFDA provided $626,500 for the procurement and transportation of 50,000 insecticide-treated mosquito nets to flood-affected populations. In all flood- and cyclone-affected provinces, the INGC, international NGOs, and U.N. agencies are responding to water, sanitation, and hygiene concerns through the distribution of Certeza, a locally produced water purification product. To mitigate the spread of disease, the U.N. Population Fund, in coordination with the GRM's Ministry of Health, has distributed hygiene kits in accommodation centers. These are all good examples of international cooperation for health protection.

To address emergency food needs, UNICEF provided food assistance to 110,000 people in flood-affected areas along the Zambezi River and 32,000 people in cyclone-affected areas in southern Mozambique. In addition, WFP is providing food assistance to 140,000 people in Tete, Manica, Sofala, and Zambezia provinces and 67,000 people in cyclone-affected Inhambane Province.

In response to previous and recurrent flooding in Mozambique, the INGC has established accommodation and resettlement centers to provide temporary shelter to flood-affected families. To meet the basic needs of displaced populations, IFRC are distributing emergency relief supplies, including tarpaulins, tents, sleeping mats, water containers, soap, and ITNs, to more than 23,000 families.

4. Summary and Conclusions

In 2000 when a cyclone hit the coast, the country descended into a humanitarian crisis. In all, 800 people lost their lives and hundreds of thousands were left homeless. In 2007, the death toll was far smaller, at 29 people. Although the floods of 2007 were less severe than those of 2000, another factor explained the difference in the number of fatalities: in 2007, Mozambique was prepared. Well before the floods came in 2007, the INGC was putting measures in place to deal with them. An early warning system alerted the Institute in October to the likelihood of intense rains, and by December actions were being taken on the ground. Supplies of food and medical items were stockpiled, vulnerable people were evacuated to safer areas and a network of local centres was set up to coordinate emergency operations. When the floodwaters began to rise, the effects were devastating, and the international community rallied to provide aid, but a crisis similar to that of 2000 was averted. A rapid flow of information is the essence of disaster prevention. The first communication centre was established by Telecoms Sans Frontieres (TSF) at the NDMI office in Caia District on 15th February. This centre was used by the different organisations working in the area such as Oxfam, World Vision, Red Cross, WFP, UNICEF.

The Red Cross, USAID and other organisations worked hard to distribute basic commodities, foods and medical assistance during the emergency period. The coordination between the Mozambican government represented by the NDMI and the partner organizations improved during the emergency period. Different government agencies and Non Governmental Organizations (NGOs), UN agencies were involved in emergency operations. The NDMI prepared the population with an early warning system, emergency aid centres and coordination channels which can be considered to have been effective during the flood event. The role of NGOs and other government partners was crucial in the success of the disaster management.

After the 2000 floods national and international organizations updated their strategies to include disaster preparedness, risk management, contingency and response capacities. However the World Bank reports that there was little engagement with the communities to carry out vulnerability assessments on which to build the mitigation plans.

Institutional memory can be short when commitment to disaster reduction is not prioritized or maintained, as the disastrous effects of the collapse of the Kolka Glacier in 2002 showed, it was not expected for 30 years, so it was neither prepared for nor responded to adequately. In the case of Mozambique this commitment was not only determined by national authorities but was greatly dependent on and determined by, external agency commitment, which may wane as other priorities emerge post-disaster.

Other impacts exist from a disaster such the diversion of funds to the relief effort away from longer term development programmes; and monitoring and evaluation of the impact of the disaster on existing programmes and on the relief and recovery efforts are under prioritized.

The dependency on international agencies in 2007 in Mozambique was as heavy as it was in 2000 however the balance of control seemed to have changed, the national and regional centres having taken more responsibility, creating a much more controlled and effective response.

CCA is constrained by limited coordination and collaboration with DRM. As the example of Mozambique shows the better the DRM the more able we are to cope with the effects of climate change. Effective learning and DRM improvements made post-disaster can lead to better CCA and an improved response and reduction in risk to the next disaster.

CCA needs to be achieved through the understanding of vulnerability in all sectors (social, infrastructure, production and environmental) and this knowledge needs to be used for the formulation of preparedness and response mechanisms.

The government in Mozambique introduced new DRM structures between 2000 and 2007 illustrating the flexibility needed to accommodate the scientific and communication systems that need to be in place to adapt to a CC driven disaster; and that this can be done in liaison with and with guidance from external agencies. However, this process needs to be iterative, and as importantly, needs to consider, learn from, and employ local knowledge and expertise for effective implementation and success.

To access this local resource it may be that endemic vulnerabilities and cultural practices need to be addressed, such as the education of women, as vulnerability is exacerbated by poor human development, which can in turn be worsened by the impact of a flood.

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Case Study 9.6. Drought, Heat Wave, and Black Saturday Bushfires in Victoria

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1. Introduction

Fires are extreme phenomena, which means that infrequent dangerous weather and climate situations can lead to major fire related disasters in spite of the huge efforts to increase fire fighting capacity and disaster risk management. Increased heat waves and droughts, and higher temperatures, particularly maximum temperatures, will very likely increase the frequency of extreme fire danger conditions and with it the probability of fire, particularly of large fires (Vázquez and Moreno 1993; Piñol et al. 1998; Viegas 1998; Pausas 2004; Trigo et al. 2006; Australian Government 2009[8]). Episodes such as in the Spanish Levant in 1994, the Republic of Korea in 2000, Portugal in 2003 and 2005, Greece in 2007 and the Australian state of Victoria and its capital Melbourne in 2009 mark unprecedented records. In addition, the increase of the ignitions in the proximity of human settlements and encroachment by vegetation of rural areas can have disastrous consequences, as attested by some of the most devastating multiple fire episodes. During the second half of the 20th century, as unproductive land was abandoned and people moved to the cities, fires became more frequent and widespread.

[INSERT FOOTNOTE 8 HERE: The final report from the Australian Government is expected in July 2010 and this report will be updated dependent on that report.]

In this case study, risk and impacts in Victoria and response actions to reduce risk and damages regarding on drought, heat wave and fires are presented for cases in Melbourne and the state of Victoria. The cases of fire in Europe and Republic of Korea are also described to find similarity of risk and impact of fire in other regions and good response action or early warning system and management system. The relationship between extreme events such as drought, heat wave and fires and climate change; and information and warning system, decision-making abilities and GIS based risk management on disaster risk reduction are also summarized. For reducing potential impact of wildfires and landslides on burned areas and adapt climate change, land-use and land cover changes, post-fire vegetation recovery and recovering ecosystem resilience are also discussed.

2. Victoria and Melbourne Case

2.1. Meteorological backgrounds

Victoria has a varied climate despite its small size which it ranges from semi-arid and hot in the north-west, to temperate and cool along the coast. Air from the Southern Ocean helps reduce the heat of summer and the cold of winter. Melbourne and other large cities are located in this temperate region. The Mallee and upper Wimmera are the warmest regions with hot winds blowing from nearby deserts. Average temperatures top 30 °C during summer and 15 °C in winter and the highest maximum temperature of 48.8 °C was recorded in Hopetoun on 7 February (Bureau of Meteorology 2009). The Victorian Alps in the northeast are the coldest part of Victoria. Average temperatures are less than 9 °C in winter and below 0 °C in the highest parts of the ranges with the lowest minimum temperature of –11.7 °C at Omeo on 13 June 1965 and again at Falls Creek on 3 July 1970 (Bureau of Meteorology 2009). Victoria is the wettest Australian state, after Tasmania, where rainfall increases from north to south, with higher averages in areas of high altitude. Median annual rainfall exceeds 1,800 mm in some parts of the northeast but is less than 250 mm in the Mallee. Rain is heaviest in the Otway Ranges and Gippsland in southern Victoria and in the mountainous northeast. Snow generally falls only in the mountains and hills in the centre of the state. Rain falls most frequently in winter, but summer precipitation is heavier. Highest recorded daily rainfall in Victoria was 375 mm at Tanybryn in the Otway Ranges on 22 March 1983 (Bureau of Meteorology, 2009).

2.2. Geological backgrounds

Victoria is the second most populous state in Australia and has a highly centralised population with over 70% of Victorians living in Melbourne. Victoria's northern border is the southern bank of the Murray River which also rests at the southern end of the Great Dividing Range, stretches along the east coast and terminates west of Ballarat. It is bordered by South Australia to the west and shares the shortest land border with Tasmania. Victoria contains many topographically, geologically and climatically diverse areas, ranging from the wet, temperate climate of Gippsland in the southeast to the snow-covered Victorian alpine areas which rise to almost 2,000 m with Mount Bogong the highest peak at 1,986 m. The Alps are part of the Great Dividing Range mountain system extending east west through the centre of Victoria. There are extensive semi arid plains to the west and northwest. There is an extensive series of river systems in Victoria such as Murray River, Ovens River, Goulburn River, King River, Campaspe River, Loddon River, Wimmera River, Elgin River, Barwon River, Thomson River, Snowy River, Latrobe River, Yarra River, Maribyrnong River, Mitta River, Hopkins River, Merri River and Kiewa River system.

In 2006, there were 8.3 million hectares of forest in Victoria covering 36% of the State. This included 7.8 million hectares of native forest, which accounted for 95% of the total forest area, and 441,000 hectares of plantations. Eucalypt forest types accounted for 93% of Victoria’s total native forest area. The most common eucalypt forest types were eucalypt medium open, mallee woodland, eucalypt tall open, and eucalypt medium woodland. The most common non-eucalypt forest type was casuarina which accounted for 2% of the total native forest. There was 619,000 hectares of old-growth forest in 2006, or 11% of the total eucalypt forest assessed. Fire is the main threat to old-growth forest in Victoria, with bushfires destroying over 100,000 hectares of old-growth between 2003 and 2006. A total of 145 forest dependent fauna species have been identified as threatened or extinct in Victoria. This includes 9 extinct, 10 regionally extinct, 19 critically endangered, 31 endangered, 37 vulnerable and 39 near threatened species. Fire is an important part of many forest ecosystems in Victoria. Much of Australia’s flora and fauna has evolved with fire and rely on particular fire regimes for continued survival. Since European settlement, the timing, frequency and intensity of fires have changed. These changes can significantly impact on the health of Victoria’s native forests.

2.3. Event summary

During this period, there had been areas with very little above average rainfall but most of Victoria received either below or well below average rainfall. Victoria has experienced a decline in average rainfall of 14 % (DSE 2008). A large portion of southern Victoria, notably the area that surrounds Melbourne, received the lowest rainfall on record.

A heat wave commenced in late January of 2009 and led to record-breaking prolonged high temperatures in the southeastern Australia region. The highest temperature recorded during the heat wave was 48.8 °C in Hopetoun, Victoria, a record for the state (National Climate Centre 2009). While Adelaide and Melbourne cities broke records for the most consecutive days over 40 °C, Mildura, Victoria recorded an all time record 12 consecutive days over 40 °C. The exceptional heat wave was caused by a slow moving high-pressure system that settled over the Tasman Sea, with a combination of an intense tropical low located off the North West Australian coast and a monsoon trough over Northern Australia, which produced ideal conditions for hot tropical air to be directed down over Southeastern Australia (National Climate Centre 2009). The heat began in South Australia on 25 January but became more widespread over southeast Australia by 27 January. A weak cool change moved over the southern coastal areas bringing some relief on January 30 (National Climate Centre 2009) including Melbourne, where the change arrived that evening, dropping temperatures to an average of 30.8 °C. Over the five days, 27–31 January 2009, maximum temperatures were 12–15°C above normal over much of Victoria (see Figure 9-1).

[INSERT FIGURE 9-1 HERE:
Figure 9-1: Maximum temperature anomalies for the period 27–31 January 2009.]

The temperature was above 43°C for three consecutive days from 28–30 January reaching a peak of 45.1°C on 30 January 2009. At the time, Melbourne’s maximum temperature of 45.1°C on 30 January 2009 was the second-highest on record behind 45.6°C on 13 January 1939 (subsequently surpassed on Saturday 7 February 2009, which reached 46.4°C). Overnight temperatures were also extremely high with Melbourne Airport's minimum of 30.5°C on the 29th January only 0.4°C short of the Victorian record. The extremely high day and night temperatures combined to make a record high daily mean temperature of 35.4°C on 30 January with average of maximum day and minimum night temperature in Melbourne which daily mean temperature has exceeded 35°C was the first time (State Government of Victoria 2009). The heat wave generated extreme fire conditions during the peak of the 2008-09 Australian bushfire season, causing many bushfires in the affected region, contributing to the extreme bushfire conditions on February 7, also known as the Black Saturday bushfires. A study by the Australian Bureau of Meteorology and the CSIRO which found that fire-weather risk is likely to increase at most sites considered from 2020 to 2050 was cited in support (Hennessy et al. 2009).

The Black Saturday bushfires were a series of bushfires that ignited or were burning across the Australian state of Victoria on and around Saturday 7 February 2009 during extreme bushfire-weather conditions, resulting in Australia's highest ever loss of life from a bushfire. As the day progressed, all time record temperatures were being reached, 46.4 °C in Melbourne and humidity levels dropped to as low as 6%. The McArthur Forest Fire Danger Index reached unprecedented levels, ranging from 120 to over 200. This was higher than the fire weather conditions experienced on Black Friday in 1939 and Ash Wednesday in 1983 (Bureau of Meteorology 2009). By midday, wind speeds were reaching their peak of 120 km/h and power lines were felled in Kilmore East by the high winds, sparking a bushfire that would later generate extensive pyrocumulus cloud and become the largest, deadliest and most intense firestorm ever experienced in Australia's post-European history. The overwhelming majority of fire activity occurred between midday and 7 pm, when wind speed and temperature were at their highest and humidity at its lowest.

2.4. Impacts

Drought

The most significant and inherent risk in drought is insufficient water supply for Melbourne. It is positive that Melbourne residents are aware of the scarcity of potable water and have made significant reductions in consumption in recent times. The water restriction regime of Melbourne has helped manage the significant drought issues of recent years. Central Australia has warmed 1.5 – 2.0 °C over the last century (State Government of Victoria 2009). Over the last 12 years from 1998 to 2009, Victoria has experienced warmer than average temperatures, and the last decade has been the warmest on record, breaking records going back 154 years (State Government of Victoria 2009; Parliament of Victoria 2009). During the same period, there has been very little above average rainfall and most of Victoria received either below or well below average rainfall which Victoria has experienced a decline in average rainfall of 14 % (DSE 2008). A large portion of southern Victoria, notably the area that surrounds Melbourne, received the lowest rainfall on record. The same has been experienced in western Victoria (State Government of Victoria 2009). The whole of south-east Australia suffered a severe and protracted drought which is without historical precedent (. In central Victoria the 12-year rainfall totals have been around 10 to 20 % below the 1961–90 average and 10 to 13 % below the lowest on record for any 12-year period prior to 1997 (State Government of Victoria 2009). Across Victoria the average annual rainfall during this drought has been 555 mm, compared with a long-term average (1961–1990) of 653 mm (Australian Government 2009). Rainfall deciles for January and February 2009 indicate that both months are very much below average (Australian Government 2009). Decreased water supply along with warmer temperatures is likely to increase drought risk and severity (CSIRO, 2007). As droughts become more severe fire risk is expected to also become greater. The key adaptation measures are considered to provide benefits across drought risks, this is storm water harvesting. This can assist in both flash flooding events and with insufficient water supply. As storm water volume in Melbourne is almost equal to potable water consumption, this is a valuable resource. Additional capacity in storm water harvesting can also put less pressure on drainage systems during intense rainfall events.

Heat Wave

Mortality during heat waves can be difficult to measure, as deaths tend to occur from exacerbations of chronic medical conditions as well as direct heat related illness, particularly in the frail and elderly. Excess mortality provides a measure of impact, but does not provide information specifically on underlying cause of death. The heat wave has clearly had a substantial impact on the health of Victorians, particularly the Elderly (National Climate Centre 2009; Parliament of Victoria 2009). For the week of the heat wave, 26 January to 1 February 2009, 25% increase in total emergency cases and a 46% increase over the three hottest days; 34 fold increase in cases with direct heat-related conditions; 2.8 fold increase in cardiac arrest cases; almost 4 fold increase in attendances for direct heat related conditions and almost 2 fold increase in calls to attend a deceased person. Emergency Department report that 12% overall increase in presentations, with a greater proportion of acutely ill patients and a 37% increase in those 75 years or older; 8 fold increase in direct heat-related presentations and almost 3 fold increase in patients dead on arrival (State Government of Victoria 2009; Parliament of Victoria 2009). For the total all-cause mortality, there were 374 excess deaths which a 62% increase in total all-cause mortality. The total number of deaths was 980, compared to a mean of 606 for the previous 5 years. Included in these total deaths were 179 deaths reported to the State Coroner’s Office; a 77% increase from the 101 deaths reported for the same period in 2008. Reportable deaths in those 65 years and older were more than doubled (State Government of Victoria 2009; Parliament of Victoria 2009). Khalaj, et al. (2009) identified several main diagnoses and underlying conditions for emergency hospital admission that are particularly susceptible to extreme heat events which can contribute directly to establishing health programmes that would effectively target those with higher relative risk of emergency hospital admission due to extreme heat.

Black Saturday Bushfires

A total of 173 people were confirmed to have died and total of 414 people were injured as a result of the Black Saturday bushfires (Australian Government 2009). Of the people who presented to medical treatment centres and hospitals, there were 22 with serious burns and 390 with minor burns and other bushfire-related injuries. The fires destroyed over 2,030 houses, more than 3,500 structures in total and damaged thousands more. The fires destroyed almost 430,000 hectares of forests, crops and pasture, more than 2,000 properties and over 55 businesses (Australian Government 2009). Three primary schools and three children’s services were destroyed with 47 primary schools partially damaged or requiring cleaning. The fires also destroyed over 10,000 km of fencing such as private, road and Crown land boundaries, and internal fencing were destroyed. Over 11,000 farm animals were killed or injured and over 3,550 agricultural facilities including dairies, around 211,000 tonnes of hay, wool and machinery sheds were affected by the fires. The fires affected 70 national parks and reserves, 950 local parks, 467 cultural sites, more than 200 historic places and disrupted electricity supply to 60,000 households (Australian Government 2009). Many towns north-east of the state capital Melbourne were badly damaged or almost completely destroyed, including Kinglake, Marysville, Narbethong, Strathewen and Flowerdale. Many houses in the towns of Steels Creek, Humevale, Wandong, St Andrews, Callignee, Taggerty and Koornalla were also destroyed or severely damaged, with several fatalities recorded at each location. The fires affected 78 individual townships in total and displaced an estimated 7,562 people, many of whom sought temporary accommodation, much of it donated in the form of spare rooms, caravans, tents and beds in community relief centres. Millions of animals are estimated to have been killed by the bushfires. Additionally, of the surviving wildlife, many more have suffered from severe burns. The affected area, particularly around Marysville, contains the only known habitat of Leadbeater's Possum, Victoria's faunal emblem. Forested catchment areas supplying five of Melbourne's nine major dams were affected by the fires, with the worst affected being Maroondah Reservoir and O'Shannassy Reservoir[9]. As of 17 February, over ten billion litres of water had been shifted out of affected dams into others. In early March 2009, smoke from the fires was discovered in the atmosphere over Antarctica at record altitudes[10]. The provision of health care to the injured, and then to the displaced communities, was provided by a range of health professionals, including paramedics, nurses, and doctors (Moloney 2009).

[INSERT FOOTNOTE 9 HERE: http://en.wikipedia.org/wiki/Black_Saturday_bushfires - cite_note-age_dash_save_water-166]

[INSERT FOOTNOTE 10 HERE: http://en.wikipedia.org/wiki/Black_Saturday_bushfires - cite_note-168]

2.5. Government aid

About 3582 firefighting personnel were deployed across the state on the morning of 7 February in anticipation of the extreme conditions (Department of Innovation 2009). The Victorian Bushfire Reconstruction and Recovery Authority was established three days after Black Saturday to oversee and coordinate the largest recovery and rebuilding program Victoria has ever faced. Responses to the Black Saturday bushfires included immediate community response, donations and later, international aid efforts, Government inquiries including a Royal Commission and recommendations and discussions from a wide variety of bodies, organisations, authorities and communities. Local government is a significant player in regulating and supporting townships and communities under their jurisdiction. Municipal councils to have a preventative role in leading and contributing to some initiatives aimed at helping to make their communities safer and to protect people during bushfires was recommenced after bushfires. The Commonwealth plays an important role in supporting the states and territories, particularly in the recovery phase. It continued this role after the 7 February bushfires, with considerable assistance, particularly from the Australian Defence Force.

Several of these responses are currently ongoing as of September 2009. Australia's most prominent fire ecologist, Kevin Tolhurst, is developing a new course for the University of Melbourne on fire behaviour. Later that month the City of Manningham announced it was developing the state's first integrated fire management plan in conjunction with the interim findings of the Royal Commission. Eventually all Victorian councils responsible for both urban and rural land will need to develop such plans, which define fire risks in open space areas, along major roads, and in parkland. In September/October 2009, it was announced that a new fire hazard system would replace the previous one. The new system involves a 6-tier scale to advise those in affected areas of the level of risk, activity of the fire, etc. On the highest risk days, residents will be advised to leave the potentially affected areas (Department of Innovation 2009).

3. Fires in Europe

Annual temperatures are projected to increase in southern Europe and the Mediterranean (SEM) more than the global average (IPCC 2007; Moreno et al. 2010). Maximum temperatures are also likely to increase more than average or minimum temperatures (IPCC 2007; Moreno et al. 2010). Annual precipitation is very likely to decrease in most of SEM, and the number of wet days is very likely to decrease. The number of dry spells and the risk of drought are likely to increase in SEM, notably in southern Europe (Lehner et al. 2006). By 2030 Melbourne is expected to likely be significantly affected by warmer temperatures and heat waves, lower rainfall, intense storm events and flash flooding (CSIRO 2007). Every year, approximately 50.000 fires are recorded in Europe, mainly in SEM, where they burn 0.5 MHa (San Miguel and Camia 2009). Despite similar or even more dangerous climatic conditions in the countries of the southern rim of the Mediterranean Sea, or in part of the Anatolian Peninsula, fires in these areas are fewer (Dimitrakopoulos and Mitsopoulos 2006), although Turkey suffered the largest fire in their historical records in 2008, amounting some 20,000 ha. By the late 1960’s wildfires started to occur at an increasing rate in all countries of the European Community (Alexandrian and Esnaut 1998). Area burned increased during the 1970’s and into the 1980’s, by which time Spain and Italy had reached maximum values (Moreno et al., 2010). Greece and Portugal followed suit with some delay. During this decade of transition none of the northern African countries or Turkey experienced a similar increase. Fires became more frequent during the second half of the 20th century, but also more widespread. In general, the number of large fires seems stable (San Miguel and Camia 2009), in some areas is increasing (González and Pukkala 2007). In Bulgaria, the warm and dry conditions led to 1,400 wildfires that consumed more than 58,000 hectares, destroying 73 homes. Greece also suffered from hundreds of fires during the height of the heat wave, particularly on Samos, where fire consumed one-fifth of the island.

4. Fires in Republic of Korea

The landscape of Republic of Korea is divided into five ecoprovinces, 16 ecoregions and 120 ecodistricts (Shin and Lee 2004). The Gangwon ecoregion is located in the centre of the east coast of the Republic of Korea. It is characterized as dry and very windy in spring, and is very susceptible to forest fires. In 1996, this ecoregion experienced the largest forest fire ever recorded to that time; 3762 ha of forestland were burned. The forest fire, six times bigger than fire of 1996, was occurred in Gangwon ecoregion in 2000. After the forest fire in 2000 resulted from drought, 23,448 ha of forest area rapidly burned over 9 days due to propagation under heavy winds, with a maximum instantaneous wind speed of 25 m/s (Kim et al. 2008) in Gangwon Province of Republic of Korea. The Gangwon Province are mainly composed of flammable pine trees, comprise 81% of the entire forested area (Lee et al. 2004). Therefore, this area is subject to increased risk of forest fires. The dry and windy climate caused by foehn winds during spring, and high-density planting on steep slopes of Gangwon Province, can accelerate flame propagation over a wide area. This fire increased landslides related damages increased annual precipitation, most notably from Typhoon RUSA in 2002. According to Lee et al. (2004), soil erosion and sediment outflow is significant within 1–2 years after a forest fire, and it takes about 2 years to stabilize conditions with vegetation settlement in the burned area. Chun et al. (2003b; 2003c) reported that sediment disasters in mountainous areas of Korea can be caused by factors such as forest fires, road construction, abandoned mining, devastated cemeteries, logging, and debris flow.

5. Lessons from Drought, Heat Wave, and Fires

The Victorian Government identified the need to respond to predicted heat events in the Sustainability Action Statement released in 2006 which committed to a Victorian Heat wave Plan involving communities and local government. As a part of this strategy the department has established a heat alert system for metropolitan Melbourne and is undertaking similar work for regional Victoria. A series of pilot projects have been undertaken engaging local government to develop heat wave plans that could be integrated with existing local government public health and/or emergency management plans. One of the outcomes of these pilot projects will be the production of a toolkit to assist local councils in the preparation of heat wave response plans over the period 2009 - 2010. State Government of Victoria (2009) reported that prepare for such heat wave events has resulted in the documentation of heat wave plans such as the heat wave plan for England, “Protecting Health and Reducing Harm from Extreme Heat and Heat waves (Heat wave Plan for England 2008)” and the Californian “Contingency Plan for Excessive Heat Emergencies (Contingency Plan for Excessive Heat Emergencies, 2008).”

The Victorian government intends to debate new fire related planning and building code standards. In response to the Victorian bushfires new building regulations for bushfire-prone areas have been fast tracked by Standards Australia (Bustos 2009). Victoria has no separate building code for bushfire-prone areas. In New South Wales building laws for bushfire-prone areas are incorporated in planning legislation using a 817 °C level as the assumed temperature to which houses are subject when hit by bushfire. A draft national building code for bushfire-prone areas is proposing to use 27 °C as the standard. The system integrates GIS technologies under the same data environment and utilises a common user interface to produce an integrated computer system based on semi-automatic satellite image processing (fuel maps), socio-economic risk modelling and probabilistic models that would serve as a useful tool for forest fire prevention, planning and management (Bonazountas, et al. 2007).

In Victoria, community response to bushfire is guided by a policy that directs residents to Prepare, Stay and Defend or Leave Early, known more commonly as the ‘stay or go’ policy. This policy has been developed over many years and reflects an understanding from research into past fires that with proper planning and prior preparation, most buildings can be successfully defended from a bushfire. Prior to 7 February the State Government devoted unprecedented efforts and resources to informing the community about the fire risks Victoria faced. That campaign clearly had benefits, but it could not, on its own, translate levels of awareness and preparedness into universal action that minimised risk on the day of the fires. This is a shared responsibility between government and the people. However, there were a number of weaknesses and failures with Victoria’s information and warning systems on 7 February. Relying on local knowledge, in combination with fire managers' decision-making abilities, could improve fire management options and reduce wildfire suppression costs and ecological disasters (Kalabokidis et al. 2008).

Fire occurrence may be linked to not only particular abiotic or human factors but also land-use and land-cover experienced. Fires do not burn at random the vegetation (Nunes et al. 2005) and also have preference for certain topographic locations, or distances to towns or roads (Mouillot et al. 2003; Badia-Perpinyà and Pallares-Barbera 2006; Syphard et al. 2009). In the case of the Greece fires in 2007, the risk of causalities and of direct damage to homes and infrastructures is very high in these areas of that natural vegetation is invading the old fields and getting close to the houses. In Spain, the types of vegetation burned have been changing, from more wooded dominated areas to shrub-land dominated areas (Pausas and Verdú 2005; Pausas et al. 2006). This fact, in combination with other long-term anthropogenic disturbances, may cause further fire-induced degradation beyond the resilience domain of Mediterranean ecosystems. As a consequence of this long-term human impact, most of the Mediterranean basin is now regarded as ‘degraded’ (TNC 2004). Post-fire vegetation recovery is important in itself but also because it is a major factor controlling post-fire erosion and flash flood risk (Vallejo and Alloza, 1998). High soil erosion rates are irreversible at the ecological time scale; therefore, it is a major potential impact of wildfires. Recovering ecosystem resilience in those abandoned lands would thus require breaking degradation loops and promoting secondary succession towards more mature, more resilient plant communities (Vallejo and Alloza 1998). Restoration has no easy models to use them as a reference, and many ideas need to be revisited at the light of new paleo-ecological evidence. Given the threats of changes in fire and other climate and global changes over the values at hand, not the least its distinct and rich biodiversity, the challenge of conserving these territories under the ongoing climate and land-use/land cover changes and other global changes is paramount (Fischlin et al. 2007).

By 2030, average annual temperatures are expected to rise by 0.6 to 1.1°C with slightly more warming in summer and less warming in winter and the average stream flow is likely to drop 3 - 11% by 2020 and 7 - 35% by 2050 in Melbourne (CSIRO 2007). Melbourne is expected to accommodate unprecedented population growth to become Australia’s largest capital city by 2030 and include a doubling of the population within the City of Melbourne (Australian Government 2009). The two most significant extreme events for Melbourne likely to be exacerbated by climate change are heat waves and intense rainfall events. While drought and sea level rise also have critical risks, these two priority events can have significant and devastating effects for Melbourne. There are also increasing public health issue driven by increasing numbers of vulnerable elderly and the increasing heat island effect resulting from progressive urbanization in Melbourne (State Government of Victoria 2009). Already a health issue for Melbourne, the most significant risk is the likely increased levels of heat stress and death caused by extreme temperatures and fires. Kolbe and Gilchrist (2009) reported that the health effects of particulate exposure from bushfires and these exposures are likely to increase. High rates of health effects may be experienced by populations exposed to bushfire smoke pollution. Less concerning, but still significant, risks are the potential for food borne disease in the warmer conditions, and the increased maintenance costs to support assets and infrastructure under the more extreme heat conditions.

6. Conclusions

Over the last 12 years from 1998 to 2009, Victoria has experienced warmer than average temperatures and the last decade has been the warmest on record and rainfall totals of around 10 to 20 % below the 1961–90 average. Rainfall deciles for January and February 2009 indicate that both months are very much below average. Decreased water supply along with warmer temperatures is likely to increase drought risk and severity. The January 2009 heat wave has clearly had a substantial impact on the health of Victorians, particularly the elderly. There were two major episodes of exceptional high temperatures, from 28-31 January and 6-8 February, with slightly lower but still very high temperatures persisting in many inland areas through the period in between. There were 374 excess deaths over the January 2009 Victorian heat wave. After heat wave in 2009, a series of pilot projects have been undertaken engaging local government to develop heat wave plans that could be integrated with existing local government public health and/or emergency management plans. The Victorian government intends to debate new fire related planning and building code standards.

Fire occurrence may be linked to not only particular abiotic or human factors but also land-use and land-cover experienced. The heat wave generated extreme fire conditions during the peak of the 2008-09 Australian bushfire season, causing many bushfires in the affected region, contributing to the extreme bushfire conditions on February 7, also known as the Black Saturday bushfires. Soil erosion and sediment outflow is significant within 1–2 years after a forest fire, and it takes about 2 years to stabilize conditions with vegetation settlement in the burned area. Post-fire vegetation recovery for more resilient plant communities and land-use/land cover changes are important in itself but also because it is a major factor controlling post-fire erosion and flash flood risk. Local government is a significant player in regulating and supporting townships and communities under their jurisdiction. Translate levels of awareness and preparedness into universal action is important to minimize risk on the fires. Improving of relying on local knowledge in combination with fire managers' decision-making abilities are required to reduce wildfire suppression costs and ecological disasters. The system integrates GIS technologies under the same data environment and utilises a common user interface to produce an integrated computer system based on semi-automatic satellite image processing, socio-economic risk modelling and probabilistic models that would serve as a useful tool for forest fire prevention, planning and management.

This complex incident points to the many issues driving extreme events and the need for deep understanding of disaster risk reduction focusing on management in order to prepare for and minimize the impact of climate change in the future.

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Case Study 9.7. Dzud of 2009-2010 in Mongolia

Authors: Oyun Ravsal, A. Marin , S. McCormick, M. Bhatt

1. Introduction

The most complex and long lasting phenomenon of the cold that causes real disaster for nomadic pastoralism is a Dzud. The widespread deaths of both domestic and wild animals occur in Dzud because of hunger, freezing and exhaustion. Dzud also represents a high risk to health and livelihoods of the herders, economy of the country. The larger the scale and the longer the duration of Dzud, the higher the mortality of the livestock and greater negative impacts on socio-economy [AIACC AS06, 2006]. Dzud mainly is started with summer drought, followed by ice cover in autumn and sudden spurts of heavy snowfall, long-lasting or frequent snowfall, extremely low temperatures in winter, and drifting windstorms in spring that reduce or prevent animals from grazing on pasture [Dzud 2000]. The Mongolian term Dzud denotes unusually difficult winter conditions which result in the death of a significant number of livestock over large areas of the country, a disaster Irrespective of the type of Dzud identified, Mongolian herders included in the term both the exposure to difficult weather, and the impacts thereof [Marin 2008, 2010].

2. Storm, Cold, and Snowfall

In winter of 2009-2010, the total of 81 percent of country territory was with heavy snowfall, extreme cold and snow storms, and total 97.5 thousand or (57 percent of country all) herders' households with their livestock were hit by Dzud [Mongolia Prime Minister S.Batbold speech at the Parliament, 2010b]. In February the northern part of Mongolia was colder by 3.0-6.3oC compare with climatic norms. By the end of February 90 percent of country was under snow. Snowfall was more than climatic norms, and 30-49 cm of snow was covered 40 percent of country territory [Jigmiddroj, 2010].

Drought is a pre-condition of Dzud. The summer 2009 60 percent of country was under drought and pasture was overgrazed and hay making for winter forage reserve was limited. Preparedness to winter of both herds and the herders was not appropriate - animals could not get sufficient fat and the herders could not prepare sufficient forage. In addition, winter pasturing was difficult because of snowdrift was dense and hardened, in some places with covered with ice crust [Jigmiddorj, 2010].

3. Impacts

By official information, total 8.1 million heads of livestock was lost during winter of 2009-2010. Impact of Dzud 2010 by end of April was that total 8711 households lost all their animals, 32756 households lost more than half of their animals, and more than 1400 households migrated from rural area to towns for surviving and seeking for job opportunities. [Batbold, 2010a]. Because of need for additional forage and other necessities to overcome severe winter the herders took loan from commercial banks. Nearly 41 percent of total 170 thousand herders' households are at debt equivalent to 45 millions of US dollar, 3 percent of which is debt of households those lost all their animals [S.Batbold 2010b].

4. Preparedness and Relief

Total 26.2 billion tugrug (equivalent to USD18.7 million) were spent for aid and relief activities. Resources were distributed as 36.2 percent for animal fodder, 20.6 percent for transportation, 17.3 percent for herders' medical and social services, and 16.7 percent for disposing of animal carrions to prevent outbreaks of disease, and 9.2 percent for rehabilitation of roads and mountain passes blocked by snow [S.Batbold 2010b] In April, the Government approved "General plan to overcome and recovery of losses of Dzud disaster" and "Guide for restocking of herders affected by Dzud" [http://open-government.mn].

5. Dzud

The Dzud of 1999-2000 was a combined disaster, covering 70% of the country's territory, caused serious damages to animal husbandry. Main reasons of the mass animal losses were as follows [Dzud 2000]:

- Livestock, suffered from 1998-1999 winter **black and white dzud**, was faced with the **harsh windy spring** of 1999 and **summer drought** and had no chance of getting fattened, the pasture productivity was also very low.
- After heavy snowfall in October of 1999 there was a warm spell in November and December which resulted the melting of snow and pasture was covered by icy crust (**iron dzud**).
- From the end of December the depth of snow increased blocking grazing the livestock at pasture (**white dzud**).
- Due to the extreme cold weather in January and February of 2000, a substantial number of livestock perished from starvation and exhaustion as well as from cold.
- Due to improper management for otor (move of animals to better pasture), the herders had migrated following each other that resulted **hoof dzud** (trampling of pasture) occurrence.

5.1. Dzud impacts

After 3 consequent years of dzud 2000-2002 total 12,000 of herders' families lost all of their livestock, and while thousands of families had to subsist below the poverty line. Mongolia's gross agricultural output in 2003 decreased by 40 per cent compared to that in 1999 and its contribution to the national gross domestic product (GDP) decreased from 38 per cent to 20 per cent [Dzud Impact 2004, AIACC, 2006]. Country lost nearly one third of its livestock, among which half of the total cattle and 37 percent of total horses. The GDP share of livestock falled down by 1.7 times and production of meat and milk decreased by 29 and 42 per cent respectively. Living Standard Measurement surevy of 2002-2003 showed poverty incident of 36.3 percent for the urban popualtion and 43.4 percent for the rural population [Dzud Impact 2004]. The average annual livestock mortality for the combined drought and dzuds years (18%) was 4.8% greater than the years with dzuds alone, and 7% greater than in years with only drought. Thus livestock mortality appears to be more sensitive to dzuds than to droughts, and that dzuds contributes more to livestock mortality even years where combined drought and winter storms occur [Begzsuren et., al., 2004].

5.2. Dzud risks

Multiple risks related to Dzud disaster are: (i) increasing risk to people's lives, livelihoods and health; (ii) increasing risk to infrastructure, ger and other assets; (iii) increasing death of livestock, reduction of meat and milk production and export products of animal origin; (iv) increasing risk to poverty and unemployment; and (v) increased migration of population [Dzud 2000; AIACC AS06, 2006; NCRMSAP 2009, MARCC 2009].

5.3. Dzud future projection

Climate change model projected an increase of air temperature by 4.7^{o}C and winter precipitation by from 4 to 10 percent. The harsh condition of winter will not be critical, winter index will not be lower, but summer droughts will reach an extreme increasing Dzud risk [Table 1]. Threats to large cattle (horse, camel and cattle) are going to be catastrophic Dzud index will be higher than that was in the last 60 years. In such condition, economy of pastoral animal husbandry will be problematic, and this might affect Mongolian traditional way of living and very origin of nomadic civilization [MARCC 2009].

6. Efforts to Mitigate and Reduce Dzud Losses

The lessons learned from and recommendations to reduce risk of Dzud [2000] guided Mongolia central and local governments, professional organizations, herders and donor and aid organizations to take the practical measures towards: i) Improvement of policy and legislation for animal husbandry and disaster management; ii) Capacity building of government officers of meteorological, emergency and agriculture organizations; iii) Development of rural backbone infrastructure including auto road, power supply and mobile communication; iv) Research and development of risk reduction solutions and adaptation options at local and household levels including indexed livestock insurance, early warning system, liquid gas, camel firm, improvement of the breed of livestock, etc.; and v) Sustainable livelihood of rural households and the herders labour and social care including small business, microfinance, etc.

6.1. At national level

The recent national climate change assessment report set government strategy for implementation of the adaptation measures in agriculture and water resource sectors as the following: (i) Education and awareness campaigns between the decision makers, agriculture people and public; (ii) Technology and information transfer to farmers and herdsmen; (iii) Research and technology to ensure the agricultural development that could successfully deal with various environmental problems; (iv) Management measures by coordinating information of research, inventory and monitoring. There are still many uncertainties in direct and indirect effects of climate change on natural resource base and agriculture components, in evaluation and development adaptation options and in adaptation technologies that usually require large initial investments. At the same time, the final results and benefits of any adaptation measures cannot be getting immediately. It will require a long time and great efforts [MARCC 2009].

6.2. At local level

The NCRMSAP [2009] considers importance of practical actions at the local level that addresses the real needs of those most affected by climate change, in particular women, the elderly and children, and set a goal to build climate resilience through reducing risk and facilitating adaptation in priority sectors in the short, medium and long term. Actions for facilitation of adaptation within the animal husbandry sector include the followings:

- Improve access to water and water management through region specific activities such as rainwater harvesting, and creation of water pools from precipitation and flood waters, for use with animals, pastureland and crop irrigation purposes
- Improve the quality of livestock by introducing local selective breeds that produce more and are more resilient to climate impacts
- Improve quality of livestock by strengthening veterinarian services to reduce animal diseases/parasites and cross-border epidemic infections
- Using traditional herding knowledge and techniques, adjust animal types and herd structure to be appropriate for the carrying capacity of the pastureland and pastoral migration patterns.

The multisectoral and multidisciplinary collaboration, public and private partnership, participatory approaches, the formation of community herder groups and the establishment of pasture co-management teams involving herders, local government, and members of civil society [Ykhanbai et., al., 2004], and use of advances of modern information communication technology for reaching rural herders [Oyun, 2005] are the new opportunities for implementation of adaptation at local level.

6.3. At international level

The World Bank is now trying to identify and mobilize resources to help the Government of Mongolia address the emerging disaster. The Bank representatives have met partners, including the United Nations and are taking immediate action [Arshad Sayed, 2010]:

- Exploring opportunities to tap into the World Bank's global disaster response fund
- Working within the Bank-financed Sustainable Livelihoods Program to provide support under the pasture risk management and community initiatives funds, components of the project
- Using the Index Based Livestock Insurance project which covers some 5,600 herders in the country, including in affected areas, to provide some relief to those insured.

The aim is to support an appropriate response to short-term needs and continue to deepen medium-term initiatives that reduce herder vulnerability. This can be achieved by improving pasture management and winter preparedness, the transfer and mitigation of risks from a dzud and strengthening the post-disaster response system [Arshad Sayed, 2010].

7. Relationship to Key Messages

Chapter 5: Key findings: Shared responsibilities for coping and adaptation are needed to harness local knowledge, experience, and action and integrate this into the more top-down strategies emanating from national and international disaster risk reduction/management strategies.
"Top-down" is relevant to process rather than strategy itself. Cold spell and Dzud cases show need for strengthening of peoples' health, knowledge and skills to cope with cold, improvement of households economic capacity, shelters, and grounded and demand driven "bottom-up and participatory approach".

Chapter 7: Perhaps DRM and CAA can achieve more when integrated than both separately.
Integration is needed not only for DRM and CAA, but also for social service, employment, household income and local and national economy growth, natural resource protection etc. all towards well being and sustainable livelihoods of households – basic unit of society.

8. Research Gaps and Needs

The most recent cases of cold weather extremes that introduced here were based on government official and public mass media information available on the Internet. Comprehensive scientific study of winter of 2009-2010 in Europe and Dzud in Mongolia in relation to climate change, preparedness and adaptation is needed with effort of the affected countries. Not only scientific research, but also research for solutions, including findings and engineering for implementation, is needed.

Results of the implementation of recommendations, policy frameworks, and development programmes, action plans and projects have not been monitored and evaluated. There is a need to study Dzud of 2009-2010 and update lessons and recommendations of case study of Dzud 2000 in order to establish operational mechanism to reduce vulnerability of livestock sector to drought and Dzud disasters in relevance to recent findings of climate change and socio-economic development trends.

But looking to the future, other questions come to mind [Arshad Sayed, 2010]:

- Can fragile ecosystems like those in Mongolia continue to bear the burden of an ever increasing livestock herd that continues to deplete pastures and threaten long run sustainability?
- What is the balance between allowing a traditional culture to flourish yet ensuring that modern requirements –such as good quality, access to markets, and access to health and services– are provided in good measure to all, including the far flung herder?"

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Case Study 9.8. Disastrous Epidemic Disease: The Case of Cholera

Authors: Jeremy Hess, Diarmid Campbell-Lendrum

1. The 2008 Zimbabwe Cholera Outbreak

While Zimbabwe has had cholera outbreaks every year since 1998, the 2008 epidemic was the worst the world had seen in two decades, affecting approximately 100,000 people and killing well over 4,500 (Mason 2009). The outbreak began on 20 August 2008, slightly lagging the usual onset of seasonal rains, in Chitungwiza city just south of the capital Harare (World Health Organization 2008). In the initial stages several districts near Harare were affected, but in October the epidemic exploded in Harare's Budiriro suburb and the epidemic soon spread to include much of the country, persisting well into June 2009, and ultimately seeding outbreaks in several other countries (see Figure 9-2). Weather appears to have been crucial in the outbreak, as recurrent point-source contamination of drinking water sources (World Health Organization 2008) was almost certainly amplified by the onset of the rainy season, similar to other recent African outbreaks (Luque Fernandez, Bauernfeind et al. 2009). In addition to its size, this epidemic was distinguished by its urban focus and relatively high case fatality rate (CFR; the proportion of infected people who die), which ranging from 4-5% (Mason 2009) (see Figure 9-3). While other recent African outbreaks have had CFRs up to 10% (Alajo, Nakavuma et al. 2006), most outbreaks have CFRs below 1%. Underlying structural vulnerability was also central to the disastrous impacts: the government, paralyzed after a failed presidential election, had not been providing basic water and sanitation services for months, inflation was rampant, and political infighting undermined response efforts. Medical and public health staff, whose salaries no longer constituted a living wage, were extremely scarce. Harare's Central Hospital closed in November in 2008, at the epidemic's height, and clinics had no potable water and asked patients to bring their own (Peta 2008).

[INSERT FIGURE 9-2 HERE:
Figure 9-2: Regional spread of the 2008 Zimbabwe epidemic.]

[INSERT FIGURE 9-3 HERE:
Figure 9-3: Case fatality rates for Zimbabwe by district.]

2. New Understanding of Cholera's Human Ecology

Cholera has a very long history as a human scourge. The world is currently in the midst of the seventh global pandemic, which began in Indonesia in 1961 and is distinguished by continued prevalence of the El Tor strain of the *Vibrio cholerae* bacterium; the current global burden of disease is estimated at 3–5 million cases and 100,000–130,000 deaths per year (Zuckerman, Rombo et al. 2007; World Health Organization 2010). Figure 9-4 illustrates the recent global burden of disease. Primarily driven by poor sanitation, cholera cases are now concentrated in areas burdened by poverty, inadequate sanitation, and poor governance. In such regions, these and other factors can markedly amplify the impact of cholera outbreaks. A recent survey of epidemics from 1995-2005 revealed that the heaviest burden is in Africa, and that poverty, water source contamination, heavy rainfall and floods, and population displacement were the primary risk factors (Griffith, Kelly-Hope et al. 2006), as exemplified by the Zimbabwe epidemic.

[INSERT FIGURE 9-4 HERE:
Figure 9-4: Cholera outbreaks, 2007-2009.]

Our understanding of cholera ecology is evolving. Weather, particularly seasonal rains, has long been recognized as a risk factor for cholera epidemics, as the Zimbabwe case illustrates. In recent years, scientists have also assembled much new evidence of cholera's climate sensitivity, discovering common ecological drivers of cholera's presence and pathogenicity. These include, for example, the effect of the El Niño Southern Oscillation (ENSO), bringing higher temperatures, more intense precipitation, and consequently enhanced cholera transmission, in a wide range of settings. Several recent epidemics have also highlighted a link with extreme weather events. Cholera has become a prototypical climate-sensitive disease (Lipp, Huq et al. 2002; Colwell and Colwell 2004; Constantin de Magny and

Colwell 2009) and is one of a handful of diseases whose incidence has been directly associated both with climate variability, and long-term climate change (Rodó, Pascual et al. 2002). As climate change is expected to increase climate variability, bring more extreme weather events, and heighten vulnerability through increased malnutrition and population displacement in many regions, there is concern that climate change will increase cholera risk, working synergistically with the established risk factors of poverty and poor sanitation that are part of the human ecology of the disease.

3. The Risk of Disastrous Cholera Epidemics

The risk for epidemic cholera, as for any disaster, is a complex product of environmental and social factors. Moreover, *V. cholerae* is flexible and ecologically opportunistic, enabling it to cause epidemic disease in a wide range of settings and in response to climate forcings (Koelle, Pascual et al. 2005). Given this complexity and cholera's dynamic range, it is most appropriate to use several distinct epidemics to illustrate both the important climatologic drivers associated with increased *V. cholerae* exposure as well as the vulnerability factors that exacerbate risk of large, severe, prolonged epidemics. This risk can be characterized using a standard risk framework common to both public health and disaster risk management that focuses on the interactions between environmental hazards and population vulnerability, with particular emphasis on drivers of pathogen exposure, host susceptibility, and adaptive capacity.

3.1. Exposure

Cholera epidemics occur when susceptible human hosts are brought into contact with toxigenic strains of *V. cholerae* serogroup O1 or serogroup O139. A host of ecological factors affect *Vibrio cholerae*'s environmental prevalence and pathogenicity (Colwell 2002) and the likelihood of human exposure (Koelle 2009). Recent research, focused in particular on the Bay of Bengal, has highlighted several different factors that influence this exposure probability. A retrospective analysis of ENSO effects on cholera incidence in Bangladesh was the first evidence of climate change impacts on human disease (Rodo, Pascual et al. 2002). Long-term climate variability, particularly ENSO, has emerged as a particularly important driver in other ecosystems as well, and has been associated with cholera outbreaks in coastal and inland regions of Africa (Constantin de Magny, Guegan et al. 2007), South Asia (Constantin de Magny, Guegan et al. 2007), and South America (Gil, Louis et al. 2004).

The biological plausibility of the association in coastal regions was first described by Colwell, who discovered a commensal relationship between *Vibrio cholerae*, plankton, and algae (Colwell 1996). Cholera bacteria are attracted to the chitin of zooplankton's exoskeletons, which provides them with stability and protects them from predators. The zooplankton feed on algae, which bloom in response to increasing sunlight and warmer temperatures. When there are algal blooms in the Bay of Bengal, the zooplankton prosper and cholera populations grow as well, increasing the likelihood of human exposure. Precipitation levels, sea surface temperature, salinity, and factors affecting members of the marine and estuarine ecosystem such as algae and copepods also impact exposure probability (Huq, Sack et al. 2005). Many of these factors, such as the association of *V. cholerae* with chitin (Pruzzo, Vezzulli et al. 2008) and the importance of precipitation and sea level (Emch, Feldacker et al. 2008), appear to be similar across various environments, though their relative importance varies by region. In some cases, examination of these dynamics have led to surprising findings: recent research showed that the pathogenic *V. cholerae* strains responsible for cholera epidemics in Mexico in recent El Niño years have originated from marine and estuarine sources rather than from water contamination with sewage as typically assumed (Lizarraga-Partida, Mendez-Gomez et al. 2009).

A wide range of other variables are also associated with increased exposure likelihood, including weather (Hashizume, Armstrong et al. 2008), conflict (Bompangue, Giraudoux et al. 2009), population displacement, crowding (Shultz, Omollo et al. 2009), and political instability (Shikanga, Mutonga et al. 2009). Trends similar to those of coastal regions have been seen in several lake ecosystems in Africa (Olago, Marshall et al. 2007). Many of these factors are actually mediated by the more conventional cholera risk factors of poor sanitation and lack of access to improved water sources and sewage treatment.

3.2. Population susceptibility

Population susceptibility includes both physiological factors that increase the likelihood of infection after cholera exposure as well as social and other structural factors that drive the likelihood of a severe, persistent epidemic once exposure has occurred. There are several physiologic factors that affect cholera risk or severity: malnutrition and coinfection with intestinal parasites (Harris, Podolsky et al. 2009) as well as the bacterium *Helicobacter Pylori* increases the likelihood of infection; infections are more severe for people with blood group O, for children, and for those with low physiologic reserve. Waxing and waning immunity as a result of prior exposure has also been shown to have a significant impact on population vulnerability to cholera over long periods (Koelle, Rodo et al. 2005).

While physiologic susceptibility is important, however, social and economic drivers of population susceptibility persistently seem to drive epidemic risk. Poverty, for instance, is a strong predictor of risk on a population basis (Ackers, Quick et al. 1998; Talavera and Perez 2009), and political factors are often very important drivers of epidemic severity and duration. As noted above, these factors drive exposure likelihood; as the Zimbabwe epidemic illustrates, however, the presence of structural vulnerability factors often drive the epidemic severity and persistence once exposure occurs, driving disastrous impacts. Many recent severe epidemics exhibit population susceptibility dynamics similar to the Zimbabwe case described above. Similar dynamics have been observed in other poor communities (Hashizume, Wagatsuma et al. 2008), and in the aftermath of political unrest (Shikanga, Mutonga et al. 2009) and population displacement (Bompangue, Giraudoux et al. 2009), and are particularly in evidence in sub-Saharan Africa in recent years (Gaffga, Tauxe et al. 2007).

3.3. Adaptive capacity

While adaptive capacity is closely linked with susceptibility, it is important to highlight the role of adaptive capacity and conventional public health measures in mitigating severe disease and reducing the risk that an outbreak will have disastrous impacts with high CFRs and significant loss of life; it is also important to note the role of the response to a cholera outbreak in determining the potentially devastating economic impacts of a large scale epidemic. The conventional public health strategies for reducing cholera risk fall into three general categories: primary prevention, or prevention of contact between a hazardous exposure and susceptible host (promoting access to clean water and reducing the likelihood of population displacement, for instance); secondary prevention, or prevention of symptom development in an exposed host (such as vaccination); and tertiary prevention, or containment of symptoms and prevention of complications once disease is manifest (including dehydration treatment with oral rehydration therapy).

Cholera outbreaks are familiar sequelae of complex emergencies and the disaster risk management (DRM) community has much experience with prevention efforts aimed at reducing the likelihood of cholera epidemics, containing them once they occur, and reducing the associated morbidity and mortality among the infected. Best practices as outlined in the Sphere guidelines (The Sphere Project 2004) include guidelines for water treatment and sanitation and for population-based surveillance. Nevertheless, in the context of political disruption and large population movements, particularly in regions where cholera is endemic, the risk of epidemic disease is increased as a result of increased exposure likelihood and the high susceptibility of the displaced populations.

This was in evidence in the 2002-2003 Ugandan epidemic, which affected approximately 1,000 people and had a case fatality rate of 10.3%, and was found to be associated with rains and floods brought by El Niño (Alajo, Nakavuma et al. 2006). Recent major African epidemics in Kenya, the Democratic Republic of Congo (DRC), and Zimbabwe demonstrate other, structural drivers. Recurrent epidemics in the Lake Kivu region of the DRC, some of which were associated with floods and extreme precipitation, affected over 73,000 people and exhibited a case fatality rate of 2.2%. This series of highlight the role of complex humanitarian emergencies in driving outbreaks in areas with natural reservoirs (Bompangue, Giraudoux et al. 2009). The public health response to the 2008 epidemics in Kenya, which demonstrated a very high 11.4% case fatality rate, were hamstrung by the recent political violence that complicated an organized health sector response (Shikanga, Mutonga et al. 2009).

A cholera outbreak in Peru in 1991 highlights the potentially disastrous economic impact of a large epidemic and how the impact can be compounded by an ill-informed outbreak response strategy. It appears that the epidemic began with coastal residents exposed to autochthonous cholera in the marine environment as a result of El Niño conditions (Seas, Miranda et al. 2000), though the cholera strain that caused the epidemic appears to have originated in Africa and persisted in the marine environment until conditions were more favourable for an epidemic (Lam, Octavia et al. 2010). The epidemic then grew through contaminated water supplies in the typical fashion to include over 530,000 cases and 4,700 deaths in nineteen countries by 1992 (Swerdlow, Mintz et al. 1992). The epidemic caused devastating losses to Peru in terms of loss of productivity and wages of approximately $100 million US (in 1991 dollars). The international response to the epidemic included an effective quarantine in the form of import bans on Peruvian products of marine and plant origin as well as a dramatic drop in tourism to the country, which caused another $175 million in losses (Petrera and Montoya 1992). This case illustrates the potentially dramatic impacts an outbreak can have on a developing economy and the potential to exacerbate those impacts through a maladaptive response.

4. Disease Risk Management

The global burden of disease from cholera and other climate sensitive diseases is substantial. While cholera is a prototypical climate-sensitive diarrheal disease, other aetiologies of diarrheal disease are more common and cause a significantly larger burden of disease. Many other common diarrheal pathogens also exhibit climate sensitivity. Altogether, diarrheal disease causes a substantial global burden of disease, killing approximately 2.2 million people a year (World Health Organization 2008). *Ceteris paribus*, the global burden of diarrheal disease is expected to increase considerably with climate change (McMichael, Campbell-Lendrum et al. 2004). All things need not be equal, however. Recent innovations such as the rotavirus vaccine and continued improvements in sanitation will undoubtedly have an impact. Moreover, as we gain insight into the associations between climate variability, extreme precipitation events, and outbreaks of climate sensitive disease such as cholera, as well as the factors that drive extreme susceptibility among human hosts, we identify potential points of leverage where other risk management strategies can reduce risk.

The case of cholera provides several examples from which we can extrapolate to other disease control efforts: Enhanced understanding of cholera ecology has enabled development of predictive models that perform relatively well (Matsuda, Ishimura et al. 2008) and fostered hope that early warning systems based on remotely sensed trends in sea surface temperature, algal growth, and other ecological drivers of cholera risk can help reduce risks of epidemic disease, particularly in coastal regions (Mendelsohn and Dawson 2008). Strategies to reduce physiologic susceptibility through vaccination have shown promise (Calain, Chaine et al. 2004; Chaignat, Monti et al. 2008; Lopez, Clemens et al. 2008; Sur, Lopez et al. 2009) and mass vaccination campaigns have potential to interrupt epidemics (World Health Organization 2006), and may be cost effective in resource-poor regions or for displaced populations where provision of sanitation and other services has proven difficult (Jeuland and Whittington 2009). Current WHO policy on cholera vaccination holds that vaccination should be used in conjunction with other control strategies in endemic areas and be considered for populations at risk for epidemic disease, and that cholera immunization is a temporizing measure while more permanent sanitation improvements can be pursued (World Health Organization 2010). Ultimately, given the strong association with poverty, continued focus on development may ultimately have the largest impact on reducing cholera risk.

5. The Role of Learning

From the perspective of climate change adaptation, these innovations are important, but equally or perhaps more important are processes by which we have learned about cholera’s ecology in the last two decades. Managing disease risk, like other risk management processes, will necessarily become more iterative and adaptive as climate change introduces greater variability into familiar systems. Single and double loop learning are important components of this iterative process.

Single loop learning, in which adjustments are made in response to the difference between what is expected and what is observed, can be crucial, particularly in crisis situations. The established guidelines for identifying and containing a cholera outbreak in a displaced population are an example of an effective single loop learning process. Single loop learning often glosses over root causes, however, in the effort to return to the status quo. As the World Health Organization states, "Current responses to cholera outbreaks are reactive, taking the form of a more or less well-organized emergency response", and prevention is lacking (World Health Organization 2006).

Double loop learning, however, in which the deeper assumptions, structures, and policy decisions that shape risk are examined, opens the possibility of more fundamental shifts. In the case of cholera, double loop learning is exemplified by our recent leaps in understanding of cholera ecology, which have opened the possibility of devising warning systems and other novel risk management strategies. Another equally important conclusion – one that experts on climate's role in driving cholera risk have emphasized (Pascual, Bouma et al. 2002) – is that poverty and political instability are the fundamental drivers of cholera risk, and emphasis on development and justice are risk management interventions, as well.

6. Key Messages

- Variability in precipitation and temperature can affect important epidemic diseases such as cholera both through direct effects on the transmission cycle, but also potentially through indirect effects, for example through population displacement.
- If other determinants remained constant, climate change would be expected to increase risk by increasing exposure likelihood – through increased variability in precipitation and gradually rising temperatures and by increasing population vulnerability – through increased population displacement.
- The health impacts of cholera epidemics are very strongly mediated through individual characteristics such as age and immunity, and population level social determinants, such as poverty, governance, and infrastructure.
- Experience from multiple cholera epidemics demonstrates that non-climatic factors can either exacerbate or over-ride the effects of weather or other infection hazards.
- The processes of Disaster Risk Management and preventive public health are closely linked, and largely synonymous. Strengthening and integrating these measures, alongside economic development, should increase resilience against the health effects of extreme weather, and gradual climate change.

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9.3.2. Vulnerable Regions and Populations

Case Study 9.9. Vulnerable Coastal and Mega Cities

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1. Introduction

Cities are one of the major key drivers of climate change due to their high energy consumption, land use, waste generation and other activities that result in the release of the vast majority of greenhouse gases. Cities cover less than 1% of the earth surface, but settled by around 50% of the world population (WWF, 2009). At the same time, it is cities, and in particular the urban poor, in the developing world, that are most vulnerable to and have the least resilience against, for example, heat wave, air pollution, and natural disasters such as storms, floods, and droughts [UEPB 2009].

Many low-lying coastal, river-delta mega-cities (e.g., Adelekan, 2006), already stressed by rapid population growth and economic, social, health and cultural difficulties, are now increasingly vulnerable due to climate change leading to increased risk of disasters that will affect not only the cities but the regions. An OECD report has ranked cities (Nichols et al., 2008) in terms of population and other exposures. The IPCC (Nichols et al., 2007) concludes: "*The impact of climate change on coasts is exacerbated by increasing human-induced pressures (very high confidence)";* and *"Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity (high confidence)."*

The research results will be enhanced capacity of coastal cities to better cope with risks posed by the combined effects of climate change, including sea level rise, and urban growth and development. The research approach will be to integrate climate change adaptation and disaster risk reduction approaches (McBean and Ajibade, 2009) towards building disaster resilient cities where resilience is defined as "*the capacity of a system, community or society to resist or to change in order that it may obtain an acceptable level in functioning and structure"* (UN International Strategy for Disaster Reduction definition). The UN International Strategy for Disaster Reduction (ISDR) Global Assessment Report (2009) recommended a risk reduction approach and concluded that "*investing today to strengthen capacities is essential if future generations are to enjoy a safer tomorrow*." The international START and its Cities at Risk project (Fuchs, 2009; Snidvongs et al., 2003), Integrated Research on Disaster Risk international program (IRDR, 2008) UNESCO International Centre for Water Hazards and Risk Management (ICHARM)(Japan) and other agencies have all identified coastal cities as a research foci.

2. Background

Global average sea-level is now rising faster than earlier predictions (Copenhagen Diagnosis, 2009) such that by 2100, global sea-level rise in a world of unmitigated greenhouse emissions may well exceed 1 meter with the upper limit ~ 2 meters. Sea level will continue to rise for centuries after global temperatures have been stabilized, and several meters of sea level rise must be expected over the next few centuries. Even minor sea level rise has significant societal and economic impacts through coastal erosion, increased susceptibility to storm surges and resulting flooding, ground-water contamination by salt intrusion, loss of coastal wetlands, and other problems. There has been a substantial upward trend in the severity of tropical cyclones (hurricanes and typhoons) since the mid-1970s, with a trend towards longer storm duration and greater storm intensity, strongly correlated with the rise in tropical sea surface temperatures. A further increase in storm intensity is likely to result in more heavy rain and wind events, leading to higher storm surges and risks of river flooding. In mid-latitudes, rainfall has increased overall, while it has declined in the Northern Hemisphere subtropics. Rains are also becoming more intense in already-rainy areas and recent changes are happening even faster than predicted, raising the possibility that future changes could be more severe than predicted. A common theme in the Copenhagen Diagnosis (2009) is that changes are happening more rapidly than earlier predictions so that a risk management approach will be necessary in planning adaptation strategies for coastal cities. Adaptation strategies for vulnerable areas need to be a priority (Schipper and Burton, 2009). There is need to build capacity to deal with climate-related hazards (McBean and Rodgers, 2010) combined with disaster risk reduction approaches.

People living in slums, without adequate urban infrastructure, are particularly vulnerable and will be amongst those that suffer the most from the adverse effects of climate change. Rising temperatures coincide with increased energy use for cooling. Loss of green cover in cities, in the form of parks, trees and agricultural land, raises urban temperatures, as well as contributing to climate change [UEPB 2009]. However steps are being made seen especially in China where as of 2009, 40 eco-cities were in development (4 smart-grid pilot cities, 21 LED-street-light cities, 13 electric-vehicle cities). "Last year the central government banned the distribution of free plastic bags in grocery stores eliminating 3 billion bags every day, and the consumption of 5 million tons of refined crude oil every year for plastic bags alone[11].

[INSERT FOOTNOTE 11 HERE: http://blogs.nationalgeographic.com/blogs/news/chiefeditor/2010/06/china-eco-cities.html]

Cities vary in size, economic situation, geographic location, and access to resources within the country, as well as internationally. Therefore, each city's specific local conditions must be taken into account when determining the most appropriate policies for that particular city [UEPB 2009].

3. Vulnerability of Cities to Climate Change

Assessment of city vulnerability to climate change with systematic and structured way and broad participatory approach were piloted and now have been expanded for cities of developing and least developed countries by joint effort of UN HABITAT and UNEP within Cities in Climate Change Initiative (CCCI) of SCP/LA21. Below is given some outputs of these efforts in order to illustrate vulnerability of different cities in climate change and preparedness for future changes.

SOROSOGON, Philippine (2009): Sorsogon City lies at the southernmost tip of Luzon, the largest of the 7,100 islands of the Philippine archipelago and is nestled between the Pacific Ocean and the South China Sea. Of its 64 barangays (lowest level of government) covering 31,292 hectares, 37 lie along the seacoast. The city is particularly at high risk to tropical cyclones and storm surges, extreme rainfall/flooding, increased precipitation, temperature variability and sea level rise. Nine urban coastal barangays are very vulnerable to climate-induced hazards, given their location, aging and previously damaged seawalls and inadequate drainage facilities, while 24 barangays along the coast/rivers with a population of 55,452 (36.6%) risk flooding. Prevalence of red tide (poisonous algae) in Sorsogon Bay is caused by climate related changes. Adverse climate would also impact on the income of more than 50 beach resorts as well as small traders and micro-entrepreneurs linked to tourism. The disastrous combination of a city lacking the proper Disaster Risk Reduction equipment, tools and facilities and a general public that has limited knowledge on Climate Change related hazards and risks and leaves the poor (43% of city population), who mostly populate high-risk areas and are inadequately covered by social protection schemes, particularly vulnerable.

KAMPALA, Uganda, (2009): Kampala, the capital of Uganda, is located on the northern shores of Lake Victoria covering an area of 195 sq. km and is situated at an average altitude of 3,910 ft (1,120 m) above sea level. It is situated on 24 low flat topped hills that are surrounded by wetland valleys. Kampala is characterized by urban sprawl and increasing informal settlements resulting from increasing population pressure and inadequate land use planning. The settlements are located in high risk areas with poor sanitation and prone to flooding. Due to the high water table, most of the wells/springs are contaminated by fecal matter resulting in safe water coverage of only 55% that is exacerbated by inadequate solid waste collection which currently stands at 55%. Increased construction with hard paving is taking place on the hill tops and lack of water harvesting mechanisms has caused degradation of the fragile hill slopes.

There is excessive use of wood fuel as a major source of energy for cooking, over dependence on reused vehicles and use of leaded fuel leading to air, land and water pollution. Encroachment on fragile ecosystems and blockage of the drainage systems has increased the occurrence of flash floods in the city. Given these vulnerable conditions, the city dwellers are exposed to water borne diseases such as malaria, cholera and other ailments such as respiratory tract infections.

ESMERALDAS, Ecuador (2009): Esmeraldas, a medium sized coastal city located in the northwestern corner of Ecuador, covers a land area of 16,155.97 km2. The Teaone and Esmeraldas Rivers flow on one side of the city, and with the Pacific Ocean on the other side they make up the hydrological system of the canton. Esmeraldas is part of the Choco microregion that has one of the highest rates of biodiversity in the world. The annual population growth of Esmeraldas is 3.5% in comparison with the national average of 1.9%. The city and province of Esmeraldas is considered one of the most vulnerable regions to the effects of climate change in Ecuador. In 2007, almost 60% of the population lived in areas with medium to high risks of floods or landslides. Informal settlements, housing 21% of the canton's population experience devastating effects from mudslides and river overflows during the rainy season. Mangroves, which form a buffer area against the rising river levels, are gradually being lost due to logging, and main forest areas are disappearing due to accelerating deforestation and mono-crop farming. Poor management of the city's natural resources adds to the devastating consequences of climate change.

4. Adaptation and Preparedness of Cities to Climate Change

City adaptation measures vary depending on political, cultural, historical and climatic conditions. Such measures can include: placing a greater emphasis on coastal resource management, especially the protection of mangrove and natural reef ecosystems; to a concerted "hardening up" of infrastructure, including storm-drainage systems, water supply and treatment plants, protection or relocation of solid waste management facilities, energy generation and distribution systems. Coastal cities will likely need to plan for and invest in heavy physical infrastructure projects specifically related to sea-level rise. These include: sea-surge protective barriers and dams, the reconstruction of harbour facilities, better early warning and rapid response systems to prepare for disaster preparedness as well as building better levees, flood barriers and prevention facilities and improving flood and coastal defence management. In regions where droughts are more likely to occur, better water saving and water management measures will be required (UNEP, UN Habitat, 2009; Simonovic, 2009).

While the problems are as individual as the cities themselves, it was soon realized, that a common approach brought solutions applicable in different cities. Issues tackled by the cities started with the provision of basic urban services, road construction, and managing urban growth and went all the way to open spaces, coastal protection and other environmental objectives [UEPB 2009]. Hence, illustrating a CCA and DRR combined approach to mitigate hazards (Henstra and McBean, 2008). UN-HABITAT's experience dealing with sustainable urban development facilitated the local and global levels exchange with global Sustainable Urban Development Network (SUD-Net) and the Cities in Climate Change Initiative (CCCI). Partners in developing countries, are deeply concerned that their towns and cities are not well prepared for the impacts of climate change and that they are lacking the skills and resources to implement mitigation and adaptation measures. The threats climate change poses are becoming clearer and many mayors and local governments want to take action in line with their national governments or even at a faster pace [UNEP, UN HABITAT, 2009].

In addition to physical and infrastructural adaptations, a broad range of targeted vulnerability reductions also contribute to climate change adaptation. These include: local economic development strategies; better shelter options and in-situ slum upgrading; relocation of urban populations to appropriate or improved locations when in-situ upgrading is not feasible; as well as better health facilities and better public health interventions and additionally, the improvement of agricultural production systems including the promotion of urban agriculture and strengthening rural-urban linkages [UNEP, UN Habitat, 2009].

However it is important to acknowledge that because of their concentrated form and efficiencies of scale, cities offer major opportunities to reduce energy demand and minimize pressures on surrounding lands and natural resources. If cities can harness the energy and creativity of their citizens and build on the inherent advantages that urbanization provides, they can, in fact, be part of the solution to the global problems of poverty and environmental degradation. [http://www.wri.org/publication/content/8570]

4.1. Case on Sorsogon City, Philippine

In 2008, UN-HABITAT started a pilot project in the city on building climate-resilient human settlements. By "designing and building with nature" - so the project title - possibilities of climate change adaptation for coastal cities is to be explored. As a first step, a climate change vulnerability and adaptation assessment was conducted and presented at city-wide stakeholder meetings. As a response, the city Mayor set up a technical working group comprising of municipal staff across key municipal departments. Based on the vulnerability assessment, the team developed a comprehensive climate change action plan that include the adaptation of land use plans, zoning regulations over the development of appropriate shelter plans, disaster risk reduction and the set-up of early warning systems.

The city is currently developing a plan to rehabilitate the seawall and will benefit from technical assistance to ensure that the construction is done in an eco-efficient manner. It is envisaged to support the residents in the informal settlements with techniques that would allow them to take down the house, in case of a typhoon warning, and to reassemble it after the typhoon. Eventually the resettlement of the populations along the coast may be inevitable. The city is setting land aside and will be starting consultations with the affected populations to ensure a people friendly process.

This MDG-Fund Joint Programme in the Philippines is one example of the "UN delivering as One" to combat climate change: Jointly with UN HABITAT, UNEP, the UNDP and the Food and Agricultural Organization aim to mainstream measures for climate risk reductions into key national and local development plans. {Sorsogon, 2009); http://www.unhabitat.org/ccci

4.2. International initiatives for cities and climate change

United Cities and Local Government (UCLG) is the global voice of cities and the main local government partner of the UN, spearheading the UN Advisory Committee of Local Authorities (UCLG, 2009). The Cities for Climate Protection (CCP) campaign – operated by ICLEI - Local Governments for Sustainability - has a membership of 1100 local governments from 68 countries around the world. It provides cities with tools and assistance for policies and quantifiable implementation measures on emission reductions, better air quality and more liveable cities; and organized the first World Congress on Resilient Cities bringing together all level stakeholders around cities and climate change (http://www.iclei.org). The Local Government Climate Roadmap is a process started by global local government associations, which advocates a strong and comprehensive post-2012 climate agreement. It emphasizes the critical role of cities in implementing climate change policies.

UNEP, UN HABITAT Sustainable City Programme directly helps local authorities and their partners to achieve a well-managed urban environment as part of a sustainable urban development process that empowers all city dwellers promoting good environmental governance at all levels: (i) Locally, by supporting partners in cities to apply a well proven four stage Environmental Planning and Management Process; (ii) Nationally, by supporting national partners to replicate local-level best practices into national scale and to integrate lessons of experience into national policy and legal frameworks; (iii) Regionally, by facilitating city-to-city exchanges and technical cooperation amongst developing countries through partner networks and regional meetings; and (iv) Globally, by combining the complementary strengths of UN-HABITAT and UNEP in applying specialized expertise and synthesizing experiences for awareness building, policy formulation and national replication (UNEP, UN HABITAT, 2009).

The United Nations International Strategy for Disaster Reduction (UN ISDR) is working with its partners to raise awareness and commitment for sustainable development practices as a means to reduce disaster risk and to increase the wellbeing and safety of citizens- to invest today for a safer tomorrow. Building on previous years' campaigns focusing on education, school- and hospital safety, ISDR partners are launching a new campaign in 2010 – Making Cities Resilient – to enhance awareness about the benefits of focusing on sustainable urbanization to reduce disaster risks. The campaign will seek to engage and convince city leaders and local governments to be committed to a checklist of Ten Essentials for Making Cities Resilient and to work on these together with local organizations, grassroot networks, private sector and national authorities. (UN ISDR, 2010)

5. Relationship to Key Messages

The case study on cities and climate change is relevant to key messages of chapters 2, 4, 5, 6, 7 and 8. There are some comments:

- Chapter 5: **Terminology** "Climate smart disaster risk reduction": This terminology is not used in UN cities and climate change initiatives. They use Sustainable City Development (UN Habitat, UNEP) or "Resilient Cities" (UNISDR).
- Chapter 5: **Key findings**: "Climate smart disaster risk reduction means new organizational, institutional and governmental arrangements at sub-national to international scales, but these may constrain local actions and limit coping capacity and adaptation": New International level efforts are not limiting, but supporting local level capacity and adaptation. These efforts are to link international, regional, national and local levels to build and strengthen local capacity. New organizational, institutional and governmental arrangements are needed at all levels. New arrangements are collaboration, partnership, networking, innovation, good governance, integration of climate change adaptation and mitigation, environmental planning and management towards city sustainable development.
- Chapter 5: **Key findings**: "Shared responsibilities for coping and adaptation are needed to harness local knowledge, experience, and action and integrate this into the more top-down strategies emanating from national and international disaster risk reduction/management strategies.": "Top-down" is relevant to process rather than strategy itself. Cities and climate change cases show "bottom-up and participatory approach".
- Chapter 7: "Perhaps DRM and CAA can achieve more when integrated than both separately.": Integration is not only for DRM and CAA, but also land use and urban planning, housing and infrastructure development, environmental management etc. all towards sustainable development.

6. Research Gaps and Needs

Limitation of existing climate change projection models for cities:

- Low spatial scale (30km, national) and long term (20, 40, 100 years) projection
- Projection of average value that is difficult to understand, interpretate, evaluate, etc.
- Lack of socio-economic input, and no consideration of local specifics
- Not clear how to link outputs with governance, development program, action plan, projects, etc.
- High resolution local information is required for city level climate change
- Required city level climate change model specification:
- Downscaled to local level: Spatial resolution: up to 1-5 km and temporal resolution: 4-8 years
- On the example of high risky areas (more populated cities, slum areas, etc.)
- Open, modular, more socio-economic input and local contribution, traditional knowledge, adaptation and mitigation options, use of advance of information technology in analysis, design and developments, etc…
- Simple for socio-economic interpretation, provide policy recommendation and decision options with cost-benefit calculations, etc.

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Case Study 9.10. Small Islands Developing States

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1. Introduction

Small Island Developing States (SIDS) are small island and low-lying coastal countries that share some similar development challenges, including small but growing populations, lack of resources, remoteness, susceptibility to natural disasters, excessive dependence on international trade and vulnerability to global economic developments. SIDS are also among the most vulnerable to the impacts of climate change. In addition to susceptibility to natural disasters, they face the prospect of inundation from rising sea levels, loss of land due to coastal erosion, and contamination of agricultural land due to saltwater intrusion. Low-lying atolls are especially at risk, some from complete submersion.

In addition, they suffer from lack of economies of scale, high transportation and communication costs, and costly public administration and infrastructure, which hold back their growth and development. SIDS were first recognized as a distinct group of developing countries at the United Nations Conference on Environment and Development in June 1992. In April 1994, the first Global Conference on Sustainable Development of SIDS was convened in Barbados. The conference adopted the Barbados Programme of Action (BPoA) that set forth specific actions and measures to be taken at the national, regional and international levels in support of the sustainable development of SIDS. Currently, the United Nations Department of Economic and Social Affairs lists 52 small island developing states. These are broken down into three geographic regions: the Caribbean; the Pacific; and Africa, Indian Ocean, Mediterranean and South China Sea (AIMS). Each of these regions has a regional cooperation body: the Caribbean Community, the Pacific Islands Forum and the Indian Ocean Commission respectively, which many SIDS are members or associate members of. In addition, most (but not all) SIDS are members of the Alliance of Small Island States, which performs lobbying and negotiating functions for the SIDS within the United Nations system.

The acute-onset sea level rise event that occurred in Lukunoch Island, Micronesia in 2007 is an example of the potential extreme impacts associated with shoreline inundation and saline intrusion for low-lying island communities (Keim, 2010). The impact of the three consecutive 4-5 category tropical cyclones (hurricanes Gustav, Ike and Paloma) in less than two weeks, late summer 2008, that affected Haiti, Dominican Republic and Cuba demonstrated the region's existing vulnerability to weather-related hazards and also highlighted the importance of planning and adaptation. The most extreme example of sea level rise can be illustrated by the inhabitants of Tegua, Vanuatu who had to abandon their island in 2005. Thus, SIDS are particularly vulnerable to natural as well as environmental disasters and have a limited capacity to respond to and recover from such disasters. While SIDS are among those that contribute least to global climate change and sea level rise, they are among those that would suffer most from the adverse effects of such phenomena and could in some cases become uninhabitable. Therefore, they are among those particularly vulnerable States that need assistance under the United Nations Framework Convention on Climate Change, including adaptation measures and mitigation efforts. SIDS share with all nations a critical interest in the protection of coastal zones and oceans against the effects of land-based sources of pollution. Limited freshwater resources, increasing amounts of waste and hazardous substances, and limited facilities for waste disposal combine to make the reduction of pollution, waste management and the trans-boundary movement of hazardous materials critical issues for SIDS.

2. Vulnerability

In the disaster reduction context, vulnerability can be defined as "the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards" (UN/ISDR, 2004, definition 42). WHO (2002) defines vulnerability as "the predisposition to suffer damage due to external events". Recognising and understanding vulnerability in the context of disaster preparedness are fundamental to attempts at appropriate capacity building and long term recovery. Emergency aid, such as general food supplies, delivered by agencies outside the affected community, may be crucial at certain stages of the disaster management process. However, the content of the food rations and the manner of delivery may not always be culturally appropriate or acceptable; and aid cannot, and should not, be provided indefinitely. To enable affected communities to take steps towards self-sufficiency, international and non-governmental aid organisations need to be listening to the local community. Hoffmaster (2006) expressed the thought-provoking contention that our responses tend to focus on what we are doing for the person, rather than on persons and their vulnerability of themselves. Understanding the key vulnerabilities that have contributed to the disaster in the first place should help those who provide assistance to pinpoint why the community is unable to cope and then to try to ensure that those gaps in coping ability are targeted.

Webb & Harinarayan (1999) draw attention to the danger of making generalisations. There may not be a uniform level of vulnerability throughout an entire country, or across a continent. In 1995, hurricane Luis caused £330m in direct damages to Antigua, equivalent to 66% of GDP. This can be contrasted with a larger economy of Turkey that lost between £9 - $13bn in direct impacts from the Marmara earthquake in 1999, but whose national economy remained largely on track" (UNISDR, 2010). Despite the overall trend for the most vulnerable to be women and young children, this does not mean that all women and children are vulnerable. Nor does it mean that no one in other population groups is vulnerable. Studying trends in vulnerability over time is important as it may vary dynamically through the disaster continuum, from the acute onset where the focus is on rapid response to the rehabilitation period which is more akin to community development.

3. <u>SIDS and their Vulnerabilities</u>

Many SIDS face specific disadvantages associated with their small size, insularity, remoteness and proneness to natural hazards. These factors render the economies of these states as very vulnerable to forces outside their control - a condition which sometimes threatens their very economic viability. A relatively high GDP (or GNP) per capita of these states may conceal the reality of its vulnerabilities. Threatened by the turbulence of globalization and the uncertainties of climate change, the SIDS have been for decades struggling against the odds to develop their economies and improve the diets, health and livelihoods of their people. In a background document prepared for a Special Ministerial Conference convened by FAO in November 2005, FAO lists eight specific vulnerabilities that SIDS countries share. For example, they are all vulnerable to their environmental situations because of their narrow natural resource bases. Their remoteness and propensity for climatic related disasters limit the options SIDS have to address their natural and man-made hazards and their ability to diversify their economic activities. SIDS small national economies make them more reliant on trade and, thus, especially susceptible to external shocks. According to the above background document, SIDS have very diverse economies and levels of development between themselves, with some depending on agriculture, forestry and fisheries and others relying primarily on sectors such as tourism for their overall security. Instability in agricultural production and exports coupled with increasing dependence on food imports by SIDS has led to vulnerabilities caused by events that are often outside their control.

The economies of SIDS may also be highly vulnerable to exogenous shocks such as; fluctuation of commodity and energy prices, the erosion of preferential market access, the introduction of more stringent non-tariff barriers, and international fluctuations of interest rates. If these countries' have high levels of poverty and dependence on limited exports and sectors, as well as a weak supply-side capacity, it may heighten such vulnerabilities. The recent downturns in the global economy plus increased terrorist attacks and natural hazards have all contributed to a worldwide decline in the travel industry. This can have a dramatic effect on a SIDS if it is dependent on tourism for its income. In the Maldives, the contribution of Travel & Tourism to Gross Domestic Product is expected to decline from 63.4% (MVR10,762.6mn or US$840.8mn) in 2010 to 60.3% (MVR19,328.6mn or US$1,510.1mn) by 2020.

The remoteness and fragile economies of the SIDS, exacerbated by the exposure to such hazards as tropical cyclones, SIDS tend to obtain the majority of their income through their natural resources – sun and white sandy beaches. This attracts tourists for short periods and has led to a boom in some of these islands economies. These niche markets however can suffer at the occurrence of such hazards and become a concern for Island States. At the height of Meena and Nancy on the Cook Islands, while nationals were preparing for the cyclones, visitors were trying to demand for flights out of the country, knowing very well that aviation can be disrupted by hurricane force winds. The lesson here being that these niche markets can be affected if visitors are not made aware of the risk they have to ensure in case such events occur in vulnerable areas.

Moreover, SIDS are particularly vulnerable to the physical impacts of climate change including droughts, floods, and hurricanes. Indeed, their key economic sectors such as agriculture, fisheries and tourism are among the most susceptible to the impacts of climate change. Therefore, climate change threatens to exacerbate existing vulnerabilities and be an obstacle to their socio-economic development. The hazards associated with climate change include sea-level rise due to the thermal expansion of the world's ocean and extreme weather events caused by increasing surface temperatures of the oceans. Low-lying atoll communities, such as the Maldives and Cook Islands, are especially vulnerable (Woodroffe, 2007). (Ebi, et al 2006) As a result, small island states and particularly atoll countries are likely to experience erosion, inundation and saline intrusion resulting in ecosystem disruption, decreased agricultural productivity, increased vulnerability to extreme weather events, changes in disease patterns, economic losses and population displacement (Nurse, Sem, 2001).

Small islands are particularly susceptible to changes in atmospheric and oceanic circulation which can be especially apparent during El Niño phases. In the Pacific, El Niño events have resulted in water shortages and drought in Papua New Guinea, Federated States of Micronesia, Samoa, Tonga, and Fiji, and a greater chance of cyclones affecting Tuvalu, Samoa, Tonga, Cook Islands and French Polynesia. A warming of the ocean surface around small island states has already been detected, and this trend is expected to continue. Projections show that this warming will be accompanied by an increase in heavy rainfall events and other temporal and spatial changes in precipitation patterns, and by more intense or frequent cyclones/hurricanes. Arable land, water resources and biodiversity are already under pressure from increases in population on small island states and the unsustainable use of available natural resources.

With climate change the possible impacts on SIDS are huge but specific areas are expected to be;

- Coral reefs will be reduced by rising sea surface temperatures and acidification.
- Mangroves maybe destroyed by sea level rise and an increase in extreme weather events.
- Water resources are expected to be stressed by changes in precipitation patterns.
- Economic losses from reduced agricultural yields
- Reduction in freshwater availability due to decreased rainfall and saltwater intrusion;
- The risk of oil spills due to their proximity to shipping routes carrying large oil tankers cruise ship discharges.

4. Examples of Impacts on the Vulnerable System of SIDs and Measures Taken to Reduce the Vulnerability

As a result of torrential rain in January 2004 a serious flood occurred at Au Cap District, one of the districts on Mahe island of Seychelles. The heavy rain caused extensive damages to properties and other infrastructure. The President of the Republic put together a Task Force to study the problem and come up with solutions and associated costs. The study showed that Seychelles will need about 4 million Rupees (US$ 800,000) to remedy drainage problems in Au Cap District alone. Other than Au Cap other districts also suffered from inundation including Victoria the capital resulting in restriction of mobility on roads for pedestrians and vehicles as well as damages to properties and closure of business. The public should be sensitized about disasters and how to cope with such events. This should help to reduce panic and also contribute towards an efficient handling of the situation. Activities envisaged included: setting up early warning systems; updating the emergency management plan; a maintenance programme on drainage systems; capacity-building in emergency management and technical fields such as Hydrology and flood forecasting. The main obstacles faced were the lack of technical and financial capacity to predict flooding. The flooding caused severe economic impacts, extensive damage to properties, damages to the agriculture and businesses of which they had to claim from insurance companies and the economic impact of no action would have been catastrophic.

As in many SIDS, the availability of sufficient fresh water is a major concern for the Republic of the Marshall Islands (RMI). Since the Marshall Islands lack the financial and technical resources to implement seawater desalination for all their population, efficient sustainable freshwater recovery from groundwater has been an elusive goal. Since simple abstraction of freshwater from thin groundwater lenses, typical in oceanic atolls, often results in upward coning of saltwater, which in turn causes contamination of the water supplies, a new welling procedure was required. Thus, with the help of the United Nations and the North American National Weather Service (part of the

National Oceanic and Atmospheric Administration, NOAA) a new scavenger technology for wells was introduced. This technique was an inexpensive practical solution to prevent upward coning and contamination by saltwater when groundwater is withdrawn. In 2002 a UN DESA mission to Majuro in the RMI was conducted to demonstrate the applicability of scavenger wells in optimizing fresh groundwater recovery from thin freshwater lenses residing in oceanic atolls. The scavenger well technique proved to be of great help against saltwater contamination of withdrawn freshwater in three different test locations. Since the technique is relatively simple, it is a potential solution against saltwater contamination of freshwater lenses in a wide range of coastal regions. However finding suitable spots for the scavenger well technique requires testing and analysis. Lenses develop where topological and geological conditions permit: where the underlying rock is sufficiently permeable to allow rainwater to percolate underground, but not so porous that the infiltrated rainwater immediately drains to the sea without forming lenses.

The women in Bulelavata, a small, remote village in the Western Solomon Islands accessible only by sea, used to live a subsistence lifestyle typical of women in tens of thousands of other villages across the Pacific Islands. Then, in 1998, the community chose to begin the process of establishing an energy-for-development project. In 2001, the community-owned micro-hydro system, funded by the Australian International Greenhouse Partnerships, Caritas, and the Provincial Government, was officially opened by the Provincial Premier. The system produces 24kw and has 1.5 km of high voltage transmission line, enabling the community to sell power to the Provincial Secondary School. For the women of Bulelavata, the energy project has had some significant and profound impacts, ranging from the practical, quantifiable advantages of lighting and community income to qualitative outcomes such as solidarity and empowerment. The project design of the Bulelavata community micro-hydro scheme used a women's participatory action agenda, exploiting "action learning" (or learning-by-doing) as they were able to ground the workshops within the context of the occurring project in their lives. The workshops were comprised of policy support, female project management, female role modelling at varying levels, specific women's awareness and training workshops, visits by women to other villages, management committee positions for women, a new village institution for women, technical team leadership by women, and logistical project support teams being given equal status to technical project teams. This affirmative agenda was designed to encourage and facilitate active and meaningful opportunities for participation by the village women. It operated within existing Melanesian cultural and village religious mores while at the same time challenging the boundaries of perceived gender roles through the medium of the new technology. The Bulelavata village men say that the electricity project has changed their women; they are pleased that women are now more confident and outspoken and participate more in community development activities.

The southwest Indian Ocean (SWIO) is characterized with strong southeast monsoon variability which impacts negatively on the water resources, activities and economy of the islands. To improve a deeper understanding of the transient equatorial convective waves during southern hemisphere winter will form an important component of the research in enhancing scientific understanding on the causes and mechanisms governing climate variability in the SWIO during southeast monsoon. The results could be useful for strengthening numerical model performances in the near equatorial tropical region of the Indian Ocean. Results will be made available to forecast centres, policy makers, water resource managers, agricultural and tourist managers to ensure wide application such that national capacities related to disaster mitigation, prevention and preparedness are strengthened and future risk of climate are reduced. The final report will contain recommendations for downstream enhancements to the monitoring network to improve environmental data base in the region. Outcomes are expected to provide platforms for improved prediction skills, better water resources management, and improvement in environmental data observation in the Southwest Indian Ocean and in formulating downstream enhancement of water storage facilities. The study will make use of climate reanalysis data, ocean general circulation model (oGCM) assimilated data (ocean surface and subsurface), high resolution satellite data and insitu-data to study extreme cases of dry and wet spells in the southeast monsoon and its relation with the global–regional ocean climate environment. Numerical models will be validated and the water resource responses will be assessed. Statistical associations will be studied and predictive models for rainfall and water flow level will be developed and verified. The stability of the climate indices will also be evaluated.

In order to improve the living standards in the outer islands of Kiribati; and to reduce the migration to the capital South Tarawa, a Solar Energy for Outer Islands Project was implemented. The installation of 1710 solar home systems was completed on 18 islands; the next phase will be the installation of 96 solar systems to the maneaba (village meeting hall) on the 18 islands. After the complete installation of the solar home systems the feedback collected by the energy survey carried out by the Energy Planning Unit of the Ministry of Public Works and Utilities was as follows: 1) The households no longer worry about buying kerosene for lighting, kerosene is used in the rural areas mainly for lighting as cooking is done using fuel woods. 2) Safety from fire has been increased 3) Children and elderly house members are able to obtain lighting for themselves 4) Work can continue during the night for any income related business or school work 5) The feels secured as the lighting also provide security 6) GHG emissions is lower than using kerosene 8) The health impacts have improved as well without having to breath in kerosene fumes.

5. Analysis of Information Available about the Vulnerable Systems

In the past five years, SIDS have been dramatically been affected by hazardous events such as:

- In January 2010, the Solomon Islands were hit by a 7.2 magnitude earthquake, which resulted in a tsunami as high as 10 feet in some parts of the islands.
- The January 2009 floods in Fiji killed 11 people and left an estimated 9000 displaced.
- In September 2009 an earthquake of magnitude 8.1 hit American Samoa and caused a tsunami in American Samoa, Samoa and Tonga.
- In 2004 and 2005, hurricanes Ivan and Emily devastated Grenada, battering and destroying 90 percent of homes, and inflicting damages worth US$1.1 billion – more than twice the country's GDP.

In September 2008, three storms hit Haiti in less than 21 days, killing more than one thousand people, and leaving up to one million homeless. This left the country devastated and vulnerable to future hazards that were realised in January 2010 when a 7.3 magnitude earthquake struck. It resulted in more than 200,000 dead; 3 million displaced and will take $11.5 billion to re-build. In contrast in Cuba the human cost of the three hurricanes was only 7 persons, but the economic costs reached nearly 20 % of the Cuban GDP, around 10 000 millions of dollars (50 % due to destroyed houses) more than 0.5 millions houses affected (Cuban Government press release, Journal "Granma"). The striking difference in the scale of the human loss in these two countries illustrated that Cuba has a more extensive adaptation plan in place. It manages an effective and efficient Early Warning System and a successful Risk Reduction System designed for managing the natural and anthropogenic risks. Due to the engagement of its citizens, government to local organisation coordination, vulnerable population identification and guarantee of properties, damages to human livelihoods are dramatically reduced.

To strengthen the capacity of Pacific island countries in climate prediction, a US$ 2.2 million 3 year project is being implemented in the Pacific island countries which includes Fiji, Vanuatu, Samoa, Tuvalu, Tonga, Cook Islands, Solomon Islands, Kiribati and Niue. The project aims to upgrade the National Meteorological Services of participating island countries to enable them to provide better climate prediction support to industry government and the people of the Pacific island region. The project provided PC-based stand-alone statistical climate prediction services software SCOPIC (Seasonal Climate Outlook for the Pacific Island Countries) that are tailored as far as possible within the scope of the project to meet clients planning needs.

The latest version of SCOPIC was released in early October 2005. SCOPIC has been created and maintained by the contracted software specialist, Queensland Department of Primary Industries & Fisheries. The software is used to extract the statistical relationship between historical climate data in each country with a set of predictors (either SSTs (Sea Surface Temperatures) or SOI (Southern Oscillation Index) to produce local seasonal climate forecasts. Forecast verification can also be done by the software. The software has the flexibility to incorporate other historical input data that would enable NMS personnel and their clients to explore opportunities for extending predictions to variables such as crop production, fish catch and water resources.

The Maldives consists of 1,192 islands with at least 80 percent of them are 1 meter or less above sea level, and only three have a surface area of more than 500 hectares. These characteristics make them highly vulnerable to sea level rise and extreme storm events. Tourism, which accounts for about 33 percent of GDP, creates employment for roughly half of the population and stimulates economic activity in other sectors such as agriculture, construction, and services. About 20 percent of the population depends on subsistence fisheries. The economic and survival challenges of the people of the Maldives were evident after the 2004 tsunami caused damage equivalent to 62 percent of national GDP. As of 2009, the country still faced a deficit of more than US$150 million for reconstruction.

6. Policy and Management Practices

Adapting to climate change requires building economic resilience to cope with external shocks. Economic resilience is the "ability of an economy to recover from or adjust to the negative impacts of adverse exogenous shocks and to benefit from positive shocks". In order to build their economic resilience, SIDS need to implement actions to improve their competitiveness and enhance their supply-side capacities, while targeting environmental and social goals, and promote economic diversification to reduce the negative and augment the positive impact of climate change and achieve sustainable development. Indeed, enabling supply-side policies that facilitate the diversification of production and exports, technological upgrading, and the value added are instrumental to foster economic resilience in these countries. Trade, trade policy and rules can also play an important role in constructing and strengthening the supply-side and in enhancing and/or limiting the capacity to build economic resilience and adaptive capacities in SIDS. Indeed, through trade policy, countries could stop subsidizing polluting activities and provide incentives for innovation and diffusion of green technologies, such as non-renewable energies. Currently, however, many countries are largely subsidizing highly inefficient and polluting sources of energy generation and/or "bad" agricultural practices (from an environmental and/or social perspective). Moreover, intellectual property (IP) rights could play an important role in stimulating innovation, especially in low income countries. Although deeper analysis needs to be conducted, some research highlights that for vulnerable developing countries to diversify their production and move up the value chain, certain IP rules will need to become more flexible.

However, the vulnerability of SIDS is not just an environmental issue but has immense social and economic implications, as exemplified by the devastating consequences of many natural disasters that have occurred in the developing world, including the latest tsunami in East Asia. By the same token, the threat of climate change is not only geophysical but also poses grave risks to the social and economic viability of SIDS. Adaptation to environmental vulnerability and climate change is vital but will force difficult choices and tradeoffs in policy-making, involving, for example, further intensive coastal development or its possible limitation or restriction.. The choice is limited to remaining on the island/atoll or not.

The importance of disaster risk-reduction strategies is apparent. The need to move from post-disaster reaction to building the capacity for prevention is necessary. The establishment of early warning and information systems, including at regional and sub-regional levels is needed. The need for setting up regional climate observation systems to better enable monitoring of climate variations is also required. It has been noted that the tsunami that struck East Asia has united the world and created a political momentum that should be used to further expand international cooperation for the development of early warning and information systems within the context of broader disaster prevention efforts. But any such system must be sensitive enough to meet the needs of small States, especially the SIDS.

Disaster reduction strategies are aimed at enabling societies at risk to become engaged in the conscious management of risk and the reduction of vulnerability. It is important to acknowledge that communities may have chosen to live with this risk because the costs of mitigating them are simply unobtainable to them. Macro scale diversification needs to filter down to the root level so that vulnerable communities can obtain the means to mitigate for disasters. Therefore these policies should be culturally and gender sensitive and need the necessary political commitment. They involve the adoption of suitable regulatory and other legal measures, institutional reform, improved analytical and methodological capabilities, financial planning, education and awareness. Member States and international organizations need to ensure that development plans and poverty reduction strategies in SIDS include disaster risk assessment as an integral component and increase their investments to reduce risk and vulnerability if development gains are not to be wiped out. For disaster risk reduction to be strengthened in SIDS it needs to be both a humanitarian and a development responsibility in line with the Millennium Development Goals. Member States are encouraged to support the process of consolidation of ISDR in SIDS as an essential instrument for sustainable development.

The Development Assistance Committee (DAC) of the Organization for Economic Cooperation and Development (OECD) in 2001 provided a set of key principles for sustainable development strategies. These principles were: a) *The strategic approach* which included the consensus on long-term vision, comprehensive and integrated strategies, and strategies targeted with clear budgetary priorities; b) *The strategic process* which included the priorities based on comprehensive and reliable analysis, and incorporation of monitoring, learning and improvement; c) *Linking national and local levels* which included building on existing mechanisms and strategies, and develop and build on existing capacity; and d) *Ownership* which included Country-led and nationally-owned strategies, people-centered strategy, high-level government commitment and influential lead institutions, and effective participation.

7. Research Gaps and Needs

SIDS have ongoing projects and some are in the pipeline which will implement adaptation measures to help increase resilience to the impacts of climate change on a global, regional and national level. These projects involve strengthening of institutions, policy and regulations, but also ground-level tasks such as water storage and drought resistant crops. Many follow on from, or are acting in synergy with, projects for the mainstreaming of adaptation. Some completed adaptation projects date back to the 1990s and have published outcomes which can be used as a resource for SIDS investigating adaptation approaches. However, in spite of the wide range of adaptation options that could be successfully implemented in SIDS, there are constraints that can limit the choices of options and their implementation such as inadequate data and technical capacity, weak human and institutional capacity and limited financial resources. Mal-adaptation, caused by governments underestimating or overestimating the climate impact, can also hinder the adaptation process, since it can be used as a reason for going through with adaptation options.

8. Summary and Conclusions

SIDS will continue to be vulnerable to many forms of hazards unless a comprehensive DRR and CCA strategy is implemented into all facets of society. The coalition of these islands provides an opportunity to learn from each other and transfer knowledge especially in regards to Cuba's efficient disaster management system. However, funding will have to be made available from the governments to allow a bottom up approach to develop which may be difficult in the current economic climate and outside funding may have to be sought.

An example of DRR and CCA being incorporated is seen when CBDP (community based disaster preparedness) programme came to Wajo, Indonesia, which is heavily affected by flooding. The risk of damage by water hyacinths was reduced by building a barrier of concrete poles to prevent the plants from hitting houses. A group of selected local villagers were also trained as members of Red Cross/Crescent community based action team. New infrastructure, equipment and facilities and health-care improvements were introduced: towers for clean drinking water in the villages, the provision of information and 24-hour health centres. "Though the CBDP programme here was not directly involved with climate change in the beginning, there are components of climate change issues that PMI integrated into its preparedness, prevention and response action plans," said Arifin Muh Hadi. "There is no single climate change standard, but it should be mainstreamed or integrated into each specific programme," he continued.

Viewing DRR and CCA as separate entities will not allow for major steps to be made. They both have the same goal: to reduce risk. Education on the science of climate change and disaster management throughout all levels of society will increase the awareness of the communities to their rights in a disaster, how to mitigate one and how to re-build afterwards. This will create a culture of prevention and initiate proactive measures that decrease the risk and vulnerability of the population.

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Case Study 9.11. Vulnerable Regions: Case Study: The Arctic

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1. Introduction

In recent years, most Arctic regions have been experiencing the most rapid rates of climate warming on the planet (Anisimov et *al*., 2007; Furgal and Prowse, 2008; Huntington et *al*., 2005; McBean et *al*., 2005; Overpeck et *al*., 2005; Ford and Pearce, 2010). This rapid change exacerbates an existing vulnerability due to the fact the in the harsh climate of the Arctic, everything is designed or built with the special demands of the territory in mind (Ford, 2009; Instanes et al, 2005; NRTEE, 2009; US Arctic Research Commission Permafrost Task Force, 2003). As the climate warms, there are major implications for the society that is built upon it. Thawing permafrost could cause disruption of the ground surfaces, which could upset the structures on it (US Arctic Research Commission Permafrost Task Force, 2003). Considering the sheer number of structures, roads, railways, powerlines, piping systems and mining operations that are at risk, serious disruption could destroy large industries as well as homes and communities. Additionally, the rapid change in climate has implications for health, social and economic processes, travel, and biodiversity among others. Current lifestyles and practices are threatened. This case study will focus on two examples of vulnerability: the built environment; and hydrologic processes. Both impacts are increasingly common in many Arctic communities and may be responsible for their inability to continue to reside in their historic location or in their lifestyle, given ever-increasing vulnerability.

2. The Built Environment

The main issue surrounding the built environment in Arctic communities, is the fact that everything including infrastructure such as roads, houses and buildings, pipelines, energy transmission facilities etc have been built on the assumption that the ground would be permanently frozen. As permafrost melts, the ground is less able to support the structures and systems that are built upon it, leaving a trail of twisted and broken infrastructure (US Arctic Research Commission Permafrost Task Force, 2003). This type of problem permeates every aspect of life in Arctic region. In terms of transportation for instance, roads and bridges, airports and train rails are all vulnerable to instability once the permafrost melts (Infrastructure Canada, 2008). Additionally, ice roads are a common form of transportation during the winter months. For instance, the government of Manitoba relies on over 2,000 km of ice roads in order to supply remote communities during the winter months (Infrastructure Canada, 2008). With the warming weather and melting permafrost, ice roads are likely to soften and/or collapse entirely, requiring alternate routes to be established. While there are some alternatives to the aforementioned forms of transportation, namely barges, there are limits that cannot be overcome. For instance, the port infrastructure might not be able to accommodate the increased demands on it (NRCan, 2007). Additionally, there are numerous areas and industries that are established well inland and would not be accessible by water (NRCan, 2007). With most forms of transportation in the Arctic region thus affected by climate change, the communities of the Arctic are isolated even more so than they were (Paskal, 2010).

An additional complication is the fact that infrastructure in the Arctic regions rarely has the level of redundancy (a key factor in resiliency of most infrastructure) that is present in more Southern regions (NRTEE, 2009). When combined with the isolation of communities, these factors add to the vulnerability of the region. Having such a complex and overarching vulnerability necessarily complicates the adaptation process since efforts and funding must be dispersed in order to address the problem areas.

2.1. Case study: Kivalina, Alaska

Like many other coastal communities, the community of Kivalina, Alaska has experienced problems with coastal erosion and melting permafrost causing the collapse of buildings and crumbling infrastructure. Rates of erosion are among the highest in areas of melting permafrost (Anisimov et *al*., 2007) and permafrost-ridden coasts are the most likely to erode, as ice under the seabed and shoreline melts upon contact with the warmer air and water (Instanes et al, 2005). When added to the threat of rising sea levels, coastal erosion is a major problem for coastal communities

(Walker, 1998). Permafrost thaw was also a danger and threatens many parts of the Kivalina community. When combined, the people of Kivalina were threatened on all sides. Their infrastructure was weak and breaking apart, their coasts were eroding, sometimes so severely that houses and other buildings were gradually falling into the sea. Additionally, they were isolated, so patchwork and upgrading infrastructure became a difficult undertaking. The costs of rebuilding and repairing a community to better withstand permafrost thaw, coastal erosion and sea-level rise are debilitating (US Arctic Research Commission Permafrost Task Force, 2003). In some cases, as in Kivalina, no amount of patchwork is able to accommodate the amount of damage that was done.

Given the circumstances and the costs involved on both the relocation and the adaptation sides, the decision was made to relocate the entire community (Anisimov et *al*., 2007; Arctic Research Commission Permafrost Task Force, 2003). At an estimated cost of $54 million, the relocation was an expensive option but it would save money and hardship in the meantime (US Arctic Research Commission Permafrost Task Force, 2003).

3. Geographic Location and Hydrologic Processes

Part of the reason that the Arctic region is so vulnerable is that the geographic location allows for some extreme events, not common in other regions. One such threat is that of ice jams. Ice jams are widely distributed in most northern countries and are the reason for some cases of catastrophic flooding (Burakov et al., 2007; White et al., 2007). Ice jams occur when there are northerly flowing rivers in cold climates. As the climate changes, the occurrences and characteristics of these events are changing. One of the most dramatic natural events that take place in a river (Eliasson and Gröndal, 2008), ice jams can lead to localized and regional flooding in the area behind the blockage, and the sudden failure of an ice jam can release large quantities of water and ice that may cause damage to nearby structures, croplands, and wildlife habitat downstream. Water levels are greatly increased after the ice jam formation and ice jams often lead to impacts on human activities along the banks of the river. The mechanism of ice jams formation was described in details by Parizet (1966), Uzuner (1974), Tatinclaux (1978), Tatinclaux and Lee (1978), Beltaos et al (1983, 2000), Belikov (2004), Buzin (2007) and other researchers. The main cause of breakup-jam formation is the obstruction of the downstream movement of ice blocks by segments of still intact ice cover. An ice jam can therefore form anywhere in a river; however, there are certain geomorphic or anthropogenic features that are highly conducive to jamming. These include sharp bends and abrupt reductions in slope or flow velocity (e.g. a reservoir entrance, a river mouth, or a channel constriction). Frequently the ice jams are formed on one and the same stretch of rivers.

3.1. Case study: ice jams in Lensk, Russia

In the Russian Federation, the resulting floods have resulted in huge losses to the economy and populations of the Yakutia Republic and improved techniques for forecasting ice jams are needed (Belikov and Zaitsev, 2004). The Lena River flows mainly from the south to the north and ice jams form along its extent during the periods of ice drift; particularly so when ice cover thickness reaches 1.5-2 m. These ice jams are frequently characterized by large extent (up to 80-100 km in length) and duration, up to 5-8 days (Kiljaminov, 2007). The winter of 2000-2001 was cold with thick ice and 140% of normal snow water equivalent in the upper basin. At the beginning of May, 2001, as a result of sharply increasing air temperatures, the most destructive ice-jam flood occurred on Lena River affecting the town of Lensk. The generated freshet wave of water destroyed the strong ice cover on a 800km length of the river in 2 days. The flooding of Lensk started on May 13, 2001 when an enormous ice jam more than 15 m high formed near the Batamai Island located 40 km downstream on the river. There were many attempts to break this jam including bombardment from military helicopters and aircraft but all in vain. From May 13 to May 17 the water level of the Lena River rose by about 19 m above the average long-term value for 68 years of observation by 9.5 m (Russian Federation Nat. Report, World Conference on Disaster Reduction, 2004) and Lensk was completely flooded. Most of the inhabitants were evacuated 200 kilometers north to Mirny and there was also a large rescue operation involving 12,000 people. About 1,700 houses were totally ruined by the flood and another 400 were simply swept away by the torrent. The damage to economy in Lensk was about 4 billion Rubles (about $US150M) and the total damage to related ice-jam floods in the area that year exceeded $US240M with seven deaths and more than 50 thousand people affected.

4. The Arctic Vulnerable Region

Kivalina, Alaska and Lensk, Russian Federation are just two of many areas in the Arctic that are vulnerable to climate change. Vulnerability is defined here as *the degree to which a system is susceptible to, or unable to cope with adverse effects of stress* (McCarthy et *al*., 2005) to climate change. The accelerated rate of climate change makes adaptation efforts extraordinarily challenging due to the dynamic nature of the environment (Anisimov et al., 2007). The physical changes that will result from such extreme temperature changes will affect all aspects of society from infrastructure to traditional life and health which are interdependent (NRTEE, 2009). In the Arctic communities and inhabitants are often isolated from each other and the rest of their country, making it difficult to receive aid. Ford and Pearce (2010) provide an extensive literature review of what is known, not known and needed to be known about climate change vulnerability in the western Canadian Arctic.

5. Analysis of Information Available about the Vulnerable Systems and Role of DRR or CAA to Reduce Vulnerability and Impacts

A number of adaptation methods, in addition to relocation, have been attempted in order to stem the impacts on Arctic communities. In the coastal hamlet of Tuktoyuktak, for example, efforts to prevent erosion have been undertaken. Its location as a low-lying town with a peninsula makes it vulnerable to both permafrost thaw and the accelerated erosion that process contributes to (Lonergan et al, 1993). Weighing three options ranging from $2.8 million for an annual replenishment of the sand banks to $9.1 million devoted to concrete mats bound together with chains, the community opted to tackle the issue from this angle (Johnson et al, 2000).

Additionally, several adaptation techniques have been developed and implemented in order to repair and defend existing structures against the ever-changing earth. Several of these examples can be noted in Yellowknife, Capital of the Northwest Territories, Canada. When the local airport runway began to show signs of stress under the gradual permafrost thaw, an extensive restoration was undertaken installing an insulated liner four meters beneath a 100 metre section of the runway (Infrastructure Canada, 2008). Additionally, new bridges are being installed to act in the place of ice roads that are no longer stable (Infrastructure Canada, 2008). When bridges are not plausible, millions of dollars have been put into building all-weather roads and/or airlifting supplies into the city (Infrastructure Canada, 2008).

Other examples of adaptation techniques used to reduce the thaw and gradual warming are heat pumps, convection embankments, passive cooling systems and winter-ventilated ducts (Instanes et al, 2005; Couture et al, 2003; Smith S et al, 2001). More popular, buildings are often put on pillars (US Arctic Research Commission Permafrost Task Force, 2003). These adaptive measures are not ideal. First, they are incredibly expensive, since they attempt to retrofit existing structures. Secondly, they are not long-term solutions to a problem since they merely attempt to slow the process of warming or shifting. If climate change continues to warm the earth and air, inevitably these measures will be outgrown as the earth continues to shift beyond the projections.

Deciding whether to retrofit an older structure or design and build new infrastructure requires good projections on changing climate and implications for permafrost, sea ice and level and river flows. Barriers to adaptation, including financial resources and social-cultural issues have been identified (Ford and Pearce, 2010). Climate change adds another layer of complexity to adaptation efforts. As it is changing at an unpredictable rate and so estimations needed to determine the type of adaptive measure are often incomplete. This complication ensures that any measure introduced will merely serve as a stop gap, requiring further attention in the future, or significant expense like a relocation.

The NRTEE (2009) has provided a comprehensive report on recommendations to promote the resilience of northern infrastructure and its ability to adapt to a changing climate. It is recommended that there be a “mainstreaming” adaptation into policy and integration climate risks into existing government policies, processes, and mechanisms. One example is to ensure the effectiveness of codes and standards for infrastructure design, planning, and management to address climate risks, and that this be regularly assessed in light of new climate information. The role of private insurance in managing climate risks to infrastructure, potential changes in access to coverage of insurance as new climate risk factors emerge, and the need for mandatory disclosure of financial risks that climate change poses to the industry is also needed. Because of the specific needs of the people in the north and the north in general, there should be a dialogue and engagement between risk management practitioners (codes, standards, and related instruments; insurance; disaster management) operating in Canada's North and the climate change adaptation community.

Investigations have shown that the increase of water resources in the Basin of Lena River, as a result of climate change, will significantly increase the risk of extremely high water levels caused by ice jam formation, which may exceed current extreme values (Kimstach et al, 2004). Preventive and mitigation actions include the need to reduce the ice cover solidity by, for example, sawing the ice cover in the most dangerous areas or blackening the surface of the ice cover by ashes, dusty coal or sand. In each case, determination of the type of measures which can be applied for mitigation of negative consequences needs study.

Communities in the North need stronger adaptive capacity to deal with climate change. The vulnerability of northern infrastructure and related services is plainly evident. Reliable infrastructure is central to sustainable regional development and human security. Governments need to support community-based infrastructure-risk reduction through activities such as building awareness of the linkages between disaster management and climate change adaptation, critical infrastructure mapping, and developing and tracking of vulnerability indicators.

6. Relationship to Key Messages

There are relationships to many key messages. In the Arctic, with its complexities, risk and vulnerability are very complex and dynamic and context dependent. Responding to climate change impacts requires effective government responses and building a culture or approach to adaptation across a wide range of issues and effective disaster risk management in a changing climate will be facilitated by anticipatory strategies within and between sectors and across institutions. Clearly, adaptation and disaster risk reduction is a long term issue which requires climate smart disaster risk management.

7. Research Gaps

Though there are numerous case studies and reports on adaptation to climate change in the Arctic, there are few specific studies on permafrost thaw and infrastructure damage. Considering the importance of the industry in the Arctic, the hardship for communities of the North and the expense involved in short term, ineffective stop-gap measures, there should be more of an effort from the appropriate governments and organizations to base decisions on good research. Science is at the heart of climate change knowledge and trends. The NRTEE (2009) Ford and Pearce (2010) note the need to know more about the nature and extent of climate change in Canada's North and how it will affect infrastructure and communities. The NRTEE specifically recommends: investment in expanding the weather and permafrost data stations in Canada's North; continued investment in climate science and modelling, and in climate change impacts and adaptation research. It is important that climate change projections, and climate design values to support infrastructure decisions be regularly improved and made available.

8. Conclusion

The Arctic is a vulnerable region for many reasons. Their geographic location leaves them isolated and climate change is exacerbating permafrost thaw at an accelerated rate. The communities that inhabit the area are thus very vulnerable and, as the damages to infrastructure have already started to occur, it is important that work is done to close the research gaps and find longer-term solutions.

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Case Study 9.12. Least Developed Countries and Fragile States

Author: Justin Ginnetti

1. Description of a Vulnerable Group

Since the early 1970s, Senegal has suffered from recurring droughts and a chronically severe economic situation and in 2001 it became one of the Least Developed Countries (LDCs). Global trade factors and internal political transformation have accentuated the impacts of the degradation of the physical environment—a primary asset of a country that is dependent on its natural resources and agricultural output. Sixty percent of Senegal's population works in the agricultural sector, and 95 percent of the crops are dependent on rainfall, which has been irregular and often insufficient.

Senegal suffered from a major drought in 1972, and since then it has experienced drought in 1976, 1979 and from 1982-1986, with a record-low rainfall total in 1984. Rainfall has declined by 30-40 percent since the 1970s, destroying plant cover and aggravating wind erosion. The Cape Verde peninsula risks the erosion of up to 50 percent of its beaches, and the Saloum estuary, which is vulnerable to flooding, may lose more than half of its ecosystems by 2050.

Due to lower adaptive capacity, poor communities are more vulnerable to the negative effects of climate change, including drought, which is a concern given that climate-related disasters have become more frequent (Seck et al. 2005, UN 2009). Due to a lack of data and insufficient computational power, there are relatively few regional and sub-regional climate scenarios for Africa based on regional climate models or downscaling (Boko et al., 2007). Of the models that do exist, here is some discrepancy: some predict significant drying (which may be exacerbated by land use changes and degradation); some predict progressive wetting; and some predict more frequent extremely dry and extremely wet years (Boko et al. 2007).

In response to these potential threats, Senegal has submitted a US$ 8.6 million project proposal to the Adaptation Fund Board, a multilateral fund created by the Parties to the Kyoto Protocol. The project is intended to implement measures identified in Senegal's National Adaptation Plan of Action (NAPA) to protect agricultural livelihoods, which are concentrated in coastal areas, from erosion and saltwater intrusion (Senegal, 2010). Senegal has also sought financing from the Government of Japan's Africa Adaptation Programme to fund a US$ 3.0 million adaptation project designed to reduce the negative impacts of climate change on:

- Human health
- Poverty eradication
- Food security
- Scarce water resources
- The littoral zone (UNDP, 2010).

Both of these proposed projects build upon existing disaster risk reduction policies because the NAPAs are designed to focus on urgent and immediate needs—those for which further delay could increase vulnerability or lead to increased costs at a later stage (UNFCCC 2010).

2. Analysis of Information Available on DRR and CCA in LDCs and Fragile States in Specific Cases

2.1. Title??

Some (Tschakert, 2007) have argued that Senegal's hazard- and exposure-oriented approach is misdirected and that it should instead incorporate more non-climatic factors such as sources of livelihoods, assets, access to resources, institutional networks, education, gender, race, ethnicity, poverty and self-protection. Approaches that focus on building resilience to climatic stressors are supported by disaster trend analyses (UN, 2009). However, other studies show that economic disaster losses rise with per capita incomes—up to a certain threshold (Kellenberg and Mobarak, 2008).

Disaster risk is configured unevenly and is concentrated in the poorest countries, and among the poorest communities within countries (UN, 2009; Adger et al. 2007). For example, at the global level low-income countries represent 13 percent of the exposure and 81 percent of disaster mortality risk (UN, 2009). Small Island Developing States (SIDS) and Land-Locked Developing States (LLDCs) suffer higher relative levels of economic loss from natural hazards—and they are less resilient to those losses so that one extreme event can set back decades of development gains (UN, 2009; Kelman, 2010).

Due to low resilience, high susceptibility to harm, and limited adaptive capacity, the poor are particularly vulnerable to climate hazards and the negative impacts of climate change (Adger, 2006). Much current research has emphasized that there are multiple stressors and multiple pathways of vulnerability, particularly those that address the social and institutional dynamics of social-ecological systems—for example, while some famines may be triggered by extreme climate events such as drought or floods, vulnerability researchers have shown that famines and food insecurity are more often caused by disease, war or other factors (Adger, 2006). In short, the social and economic characteristics by which LDCs are defined (education, income and health, for example) effectively lower the threshold for extreme climate events (Adger et al 2007).

Underdevelopment and susceptibility to disasters are mutually reinforcing: disasters not only cause heavy losses to capital assets, but also disrupt production and the flow of goods and services in the affected economy, resulting in a loss of earnings. In both the short and the long-term, those impacts can have sharp repercussions on the economic development of a country, affecting gross domestic product (GDP), public finances, foreign trade as well as price indices, thus contributing further to increasing levels of poverty and indebtedness (Mirza, 2003; Ahrens and Rudolph, 2006).

2.2. Title??

Several Himalayan glacial lakes have witnessed significant expansion in size and volume as a result of rising temperatures. This increases the likelihood of catastrophic discharges of large volumes of water in events which are known as Glacial lake Outburst Floods (GLOFs). One of the most dangerous glacial lakes in Nepal had been the Tsho Rolpa lake whose size increased by 6,000 percent from the 1950s to the 1990s (Sperling and Szekely, 2005).

The Tsho Rolpa glacial lake project is an example of disaster risk reduction and anticipatory adaptation. Tsho Rolpa was estimated to store approximately 90-100 million cubic meters of water, a hazard that called for urgent attention. A 150-meter tall moraine dam held the lake, which if breached, could cause a GLOF event in which a third or more of the lake could flood downstream.

The likelihood of a GLOF occurring at Tsho Rolpa, and the risks it posed to the Khimti hydropower plant downstream was sufficient to spur the Government of Nepal to initiate a project in 1998 to drain down the Tsho Rolpa glacial lake. To reduce this risk, an expert group recommended lowering the lake three meters by cutting an open channel in the moraine. In addition, a gate was constructed to allow water to be released as necessary. While the lake draining was in progress, an early warning system was established in 19 villages downstream of the Rolwaling Khola on the Bhote/Tama Koshi River to give warning in the event of a Tsho Rolpa GLOF (Sperling and Szekely, 2005).

Local villagers have been actively involved in the design of this system, and drills are carried out periodically. The World Bank provided a loan to construct the system. The four-year Tsho Rolpa project finished in December 2002, with a total cost of USD 2.98 million from The Netherlands and an additional USD 231,000 provided by Government of Nepal. The goal of lowering the lake level was achieved by June 2002, which reduced the risk of a GLOF by 20% (Sperling and Szekely, 2005).

2.3. Title??

Malawi, another LDC, is one of the more drought-prone countries in southern Africa, and its predominantly smallholder farmers are severely affected by rainfall risk resulting in food insecurity. In the past, the government has responded to recurrent drought-induced food crises by providing ad hoc food relief. Until recently, droughts and a lack of credit have prevented Malawian farmers from planting higher-yielding seed types, but an experimental weather insurance programme (based on a precipitation index and bundled with loans) allowed farmers to access hybrid groundnut seeds. Such safety nets have allowed farmers to plant the higher-yielding seeds (Linnerooth-Bayer and Mechler, 2007).

Since 2004, the Government of Ethiopia (another LDC) and its international partners have also been piloting a weather index risk financing programme as a form of drought risk mitigation and transfer. Ethiopia's innovation was to link the short-term relief (insurance) with the Government's employment-based Productive Safety Nets Programme (PSNP), which addresses the predictable needs of chronically vulnerable groups who require assistance during the hunger gap season even in good years (Maxwell et al., 2010).

2.4. Title??

The effective use of available climate information, such as seasonal forecasts, can improve agricultural yields and reduce rural communities' vulnerability to the impacts of drought (Dilley, 2000; Challinor, 2008). For example, awareness of the impacts of El Niño on climate fluctuations in southern Africa grew during the 1990s due to the nearly continuous El Niño that lasted from 1991 through 1995. As a result of this repeated exposure, governments and the public paid greater attention and detected the phenomenon earlier when it recurred in 1997, and as a result the drought impacts were reduced (Dilley 2000). Similarly, greater computing power has led to more accurate seasonal forecasts, but for this information to be useful it must be calibrated to the appropriate context and it needs to be perceived as useful by potential beneficiaries (Challinor, 2008).

2.5. Title??

Adjusting livelihood systems to persistent drought has been slow and difficult, but over time the humanitarian community has improved its response capacity to agricultural droughts (Kates, 2000). Unfortunately, rather than focusing on livelihoods, the proposed adjustments are often technical improvements, they are sometimes contradictory, and they seldom address the locally specific factors and policies that render a country or community vulnerable to drought in the first place (Kates, 2000).

On the contrary, the bottom-up approach to disaster risk reduction and adaptation is based on enhancing the capacity of local communities to adapt their livelihoods to and prepare for extreme events (Allen, 2006; Blanco, 2006). Although climate change may be incorporated in this approach through awareness raising and the transmission of technical knowledge to local communities, bridging the gap between scientific knowledge and local application is often a challenge (Blanco, 2006).

3. Relationship to Key Messages

In most LDCs in Africa, the most pressing need is to halt the decline in agricultural yields and increase food security by producing more food and taking measures to deal with irregular rainfall through improvements in storage and distribution of agricultural products, because the relative increase in agricultural production has not been due to better production methods but mainly to territorial expansion (Davidson et al., 2003). For example, the removal of trees for agricultural reasons—the primary cause of deforestation and soil erosion—has become an essential act to meet the food needs of a rapidly growing population, and even this success is highly qualified (Davidson et al., 2003; Kates, 2000).

Although climate change seems marginal compared to the pressing issues of poverty alleviation, hunger, health, economic development and energy needs, it is becoming increasingly clear that progress toward the development goals can be seriously hampered by climate change. This is why the linkages between development and climate change now receive more and more attention in scientific and policy circles (Davidson et al., 2003; OECD, 2010).

Catastrophic and irreversible damage to humans can result even from modest changes in natural systems or relatively small climate hazards. The impact on a community depends on the latter's adaptive capacity, which is in turn shaped by the community's policies and institutions (Heltberg et al., 2008). Complicating matters, the interests of poor communities are not necessarily the same as those of poor government (Kates, 2000). Some (Kates, 2000; Carmen Lemos and Tompkins, 2008; Davies et al., 2008, Heltberg et al., 2008) have argued that policy instruments based upon social protection are best suited for adaptation and long-term risk reduction because they generate net benefits under all future climate scenarios and they are rooted in the specific needs of a particular community and can therefore build resilience by addressing the root causes of vulnerability.

Progress in carrying out analyses and identifying what needs to be and can be done can be documented, but action on the ground to mainstream adaptation to climate change remains limited, particularly in the least developed countries. National policy making in this context remains a major challenge that can only be met with increased international funding for adaptation and disaster management (Yohe et al, 2007; Ahmad and Ahmed, 2002; Jegillos, 2003; Huq et al., 2006)

Socio-economic and even environmental policy agendas of developing countries do not yet prominently embrace climate change (Beg et al., 2002) even though most developing countries participate in various international protocols and conventions relating to climate change and sustainable development and most have adopted national environmental conservation and natural disaster management policies (Yohe et al, 2007). Social and environmental (climate change) issues are, however, often left resource-constrained and without effective institutional support when economic growth takes precedence (UNSEA, 2005).

4. Research Gaps and Conclusion

Burton et al. (2002) posed 21 questions about adaptation research in order to stimulate further investigation, such as:

- What is the extent of adaptation in practice and what are the barriers, obstacles or incentives to adaptation?
- How does public policy with respect to climatic hazards relate to the economic and sustainable development policies and strategies in place?
- What are the prospects for adaptation and how much can vulnerability be reduced?
- What will be the distribution of the benefits and costs of adaptation?

Even though progress has been made answering some of these questions, many are still relevant.

In particular, one of the central problems is a better understanding of adaptation and adaptive capacity, and of the practical, institutional, and technical obstacles to the implementation of adaptation strategies (Schneider et al., 2007). Both development agencies and NGOs have developed best practices based on decades of experience, but further research is needed to analyze why these guidelines are so often ignored (James, 2010).

Central to nearly all the assessments of key vulnerabilities is the need to improve knowledge of climate sensitivity—particularly in the context of risk management—the right-hand tail of the climate sensitivity probability distribution, where the greatest potential for key impacts lies (Schneider et al., 2007). In addition, relatively few regional and sub-regional climate change scenarios have been derived from regional climate models or empirical downscaling for Africa, primarily due to restricted computational facilities and a lack of human resources and climate data (Boko et al. 2007). Global climate models are unable to simulate the teleconnections and feedback mechanisms responsible for rainfall variability in Africa, and other factors (dust aerosol concentrations, sea-surface temperature anomalies) complicate African climatology (Boko et al 2007).

There is broad recognition, especially among small island developing states whose existence is threatened by sea-level rise, that climate change is a matter of national security. However, there has been insufficient systematic analysis of climate change as a security issue, particularly on the social, economic and environmental drivers of armed conflict (Barnett, 2003).

Finally, despite renewed momentum and commitments by governments to reduce disaster risk in the face of major catastrophes, preventive approaches continue to receive less emphasis than disaster relief and recovery (Davies et al., 2008). To the extent that disaster risk reduction and are advocated as cost-effective means of preventing future negative impacts on development investments without simultaneously addressing equity and rights-based arguments, they may fail to capitalize on potential synergies (Davies et al., 2008).

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9.3.3. Management Approaches

Case Study 9.13. Risk Transfer – The Role of Insurance and Other Economic Approaches to Risk Sharing

Authors: G. McBean, P. Kovacs, R. Mechler, K. Warner, J. Linnerooth-Bayer

1. Introduction

The human and economic losses caused by climatological, hydrological or meteorological (hereafter climate-related) disasters have continued an upward trend that has developed over the last few decades (Centre for Research on the Epidemiology of Disasters (CRED) , Rodriguez et al., 2009; Munich Re Data Service NATHAN[12]; Gall et al., 2009). The enormity of the problem is outlined by Wahlström (2009) who stated "*Over the last two decades (1988-2007), 76% of all disaster events were hydrological, meteorological or climatological in nature; these accounted for 45% of the deaths and 79% of the economic losses caused by natural hazards*."

[INSERT FOOTNOTE 12 HERE: MunichRe 2006 Topics Geo - Natural catastrophes 2006 Analyses, assessments, positions. Copyright 2007 Münchener Rückversicherungs-Gesellschaft, Königinstrasse 107, 80802 München, Germany, Order number 302-05217 (available at www.Munichre.com)]

Although all countries have been impacted by natural disasters, the relative impact on human lives is usually larger in developing countries and larger in economic costs in developed countries (Mileti, 1999). Despite this trend, while the absolute dollar costs of disasters in highly-developed countries are large, the damage as a percentage of Gross Domestic Production (GDP) is much larger in the developing countries (Handmer, 2003). Further, mortality figures are a good indicator of severity of impact. In highly developed countries, the average number of deaths per disaster is 23, while the number increases dramatically to about 150 deaths per disasters in medium and to over 1000 deaths per disaster in less developed countries (Mutter, 2005). To a certain extent, this statistic can be accounted for by considering issues of population density and infrastructure quality however, this is not always the case. For instance, although an event in India or China is likely to affect more people than in one of the smaller countries, the number of victims per 100,000 inhabitants list was led by Djibouti, Tajikistan, Somalia and Eritrea (Rodriguez et al., 2009). This demonstrates that in addition to population density and area of vulnerability, the economic ability of a nation to respond is an important factor in assessing the potential impact of any natural hazard. Developing nations often have minimal preventative measures and are unable to respond adequately in the immediate aftermath. Additionally, the attempt to recover from such events may be economically debilitating as well. For instance, the events in Myanmar and Tajikistan resulted in damages exceeding 20% of their Gross Domestic Production (GDP). These results highlight the important roles of insurance and other economic approaches to risk transfer and sharing so that climate-related events do not overwhelm a country or a community of people within a country.

2. Description of Thematic Approaches

The process of recovering from extreme events is expensive and can take years or even decades. Financing mechanisms supporting economic recovery include insurance and humanitarian assistance. These systems, however, have been challenged and sometimes overwhelmed in recent years by a combination of climate change, increasing populations living in areas of risk, ageing infrastructure and other factors. This case study describes a number of recent examples seeking to strengthen and enhance the financial and humanitarian systems in place to support recovery for extreme weather events. Warner et al. (2010) provide a review of the connections between climate change adaptation and disaster risk reduction in the context of insurance and risk transfer mechanisms, which provided the basis for this case study report.

There are several examples of financial mechanisms for managing risks at different scales, from local to national to international levels. At the local level, the focus is on individual households, small-to-medium sized enterprises (SMEs), farms and similar institutions or organizations. At national, including sub-national, the focus is on governments while at the international level, development organizations, donors, non-governmental organizations and others need to be considered. Broadly-speaking**,** risk transfer mechanisms can be grouped as non-insurance and insurance mechanisms. In this case study, the main focus is on insurance mechanisms but a short description of non-insurance mechanism will be given first.

[INSERT TABLE 9-1 HERE:
Table 9-1: Examples of mechanisms for managing risks at different scales**.**]

3. Description of Risk Transfer Tools and their Relation to Disastrous Events

There are several forms of risk transfer tools (Cummins and Mahul, 2009) and these include:

- (Traditional) Insurance - is a contractual transaction that guarantees financial protection against potentially large loss in return for a premium.
- Micro-insurance (e.g., Morelli et al., 2010) - is characterised by low premiums or coverage and is typically targeted at lower income individuals who are unable to afford or access more traditional insurance. Micro-insurance tends to be provided by local insurance companies with some external insurance backstop (e.g. reinsurance).
- Catastrophe Reserve funds - are typically set up by governments, or may be donated, to cover the costs of unexpected losses.
- Risk pooling or pools - aggregate risks regionally (or nationally) allowing individual risk holders to spread their risk geographically. Through spreading risks, pooling allows participants to gain catastrophe insurance on better terms and access collective reserves in the event of a disaster.
- Insurance-linked securities - most commonly catastrophe (cat) bonds which offer an avenue to share risk more broadly with the capital markets.
- Weather insurance typically takes the form of a parametric (or indexed-based) transaction, where payment is made if a chosen weather-index, such as 5-day rainfall amounts, exceeds some threshold. Such initiatives minimise administrative costs and moral hazard and allow companies to offer simple, affordable and transparent risk transfer solutions.

4. Non-Insurance Mechanisms

In addition to humanitarian assistance and disaster relief programs from governments which provide partial assistance for those without insurance or replace public infrastructure, there are also three groupings of non-insurance mechanisms: solidarity; informal risk sharing; and savings and credit (which work for inter-temporal risk spreading). Solidarity mechanisms are those that provide help from actors with a common interest. This can include help from neighbours and local or community level organizations, through to government post-disaster assistance and/or guarantees and bailouts play important roles. Similarly, at the international level, bi-lateral and multi-lateral assistance are mechanisms through which international assistance is provided to those in need. Informal risk sharing can be done through extended family relationships and other mutual arrangements. Savings and credit approaches can work though micro-savings and credit, food storage, and national reserve funds.

5. Insurance Mechanisms

Insurance is the primary source of funds to support recovery from extreme weather events in developed countries. Today insurance covers 40 percent of disaster losses in the industrialised counties compared to only around 3 percent in developing countries (Hoeppe and Gurenko, 2006). The share is higher for homeowners and businesses, and for many events covers all of the damage incurred. In contrast, most governments and their agencies typically choose not to purchase insurance coverage for the risk of damage to public infrastructure.

However, insurance markets are only emerging in most developing nations. Affluent homeowners and businesses account for most and perhaps all of the insurance market in many countries. Public infrastructure is largely uninsured. Although a number of factors continue to constrain the rate of convergence, spending on insurance is growing faster in most developing countries than in industrial countries. One constraining factor is that property owners in developing countries have not yet have developed knowledge about insurance and its role in managing risk. In addition, the current state of insurance regulation is weak in most developing countries relative to international standards of best regulatory practice and consumers do not yet have confidence in financial institutions. To date most actions to bring insurance to the world's poorest people have initially focused on life and health insurance products, like funeral and disability coverage, and motor vehicle insurance. This may, in time, create the basis that can be extended eventually to address risks to property and crops. It is not yet clear whether the role of humanitarian assistance and international relief following a disaster, which have largely been directly to address the urgent priorities of rebuilding schools, hospitals and public infrastructure, undermines the responsibilities of the local governments to address these concerns on an ongoing basis.

6. Analysis of Information Available on the Role of Thematic Approach in Specific Cases

Over the past decade there have been a number of examples of insurance mechanisms emerging in developing countries that will support recovery from future extremes. In each area there have been encouraging signs that insurance may, over time, grow to support the risk management needs in developing countries like that in place in industrial countries. Despite the growth in this sector, there are still market gaps and failures that exist, making the contributions of national governments and the international community an important factor in disaster recovery.

6.1. Caribbean Catastrophe Risk Insurance Facility

The Caribbean Catastrophe Risk Insurance Facility (Young, 2009), the world's first regional insurance fund, was launched in 2007, with sixteen participating countries securing insurance protection against damage from catastrophic hurricanes and earthquakes, the two most serious risks in the area. Seven of the participating countries represent almost one third of the countries identified by the World Bank as experiencing the greatest economic losses from disasters during the period from 1970 to 2008 when measured as a share of GDP.

The Caribbean Facility focuses primarily on insuring participating governments seeking to pay 50 percent of the costs that the governments are expected to incur and thus provides an incentive for governments to invest in risk reduction and other risk transfer tools. The cost of participation is determined for each participating country based upon estimates of the expected risk and extent of damage. Pooling the risks of 16 countries has reduced by 40 percent the costs relative to the price each government would have paid if they negotiated individually in the commercial insurance market. Funding for the program is the responsibility of participating countries and has largely been supported a donor conference hosted by the World Bank.

The experience with the Caribbean Facility shows that programs must reflect the needs of the participating countries. Severe weather risk is a growing dimension of the risks facing governments in developing countries but there will be circumstances where it is appropriate to establish mechanisms that also address other hazards. The Facility also provides an example where international assistance can be provided to support disaster management yet designed to support a transition where local government assume a possibly growing responsibility.

6.2. Micro-insurance

A recent report (Morelli et al., 2010) has reviewed the role of micro-insurance in disaster risk management. There are many examples of micro-insurance emerging to cover life, health and motor insurance needs in developing countries, but the application to disaster risk management is only beginning. Loster and Reinhard (2010) focus on the relationship between micro-insurance and climate change. Most examples of micro-insurance involve organizations active in communities without insurance that develop insurance products and evolve this into formal insurance companies. While some early micro-insurance companies operate on a for profit basis, many are not for profit. Most are based on the expectation that the pool of participants will provide payments that cover the costs incurred, including expected damage claims, administrative costs, taxes, regulatory fees, etc. The expected damage claims from most people with low incomes are very low because claim events are rare, by definition, and these people typically have fewer possessions that may be damaged.

A major challenge for the micro insurance operations that have been established recently has been controlling the cost of administration. Some organizations have addressed this issue by selling insurance to groups of people. Some programs are linked to loans, increasing their credit-worthiness. Bhatt et al (2010) describe the how micro-insurance has emerged in a policy environment that has made recent progress towards disaster risk reduction and can put cash into the hands of affected poor households so they can begin rebuilding livelihoods. Recent insurance regulatory reforms within the Indian Government and the prioritization of risk reduction by national and global practitioners have contributed to the viability and advancement of micro-insurance for the poor. In Malawi, smallholder farmers can purchase index-based drought insurance linked to loans used to enhance their farm productivity. An index-based insurance program in Bolivia promotes risk reduction by encouraging farmers to assess their practices relative to a reference farmer to determine if poor outcomes are due to environmental factors, triggering an insurance payout, or other factors within the farmer's control.

6.3. Index-based insurance in Bolivia

The Fundación PROFIN has developed a scheme in four provinces in the north and central Altiplano regions of Bolivia that combines incentives for pro-active risk reduction and an insurance index mechanism. In this scheme the index is based on the production levels of reference plots of farmland in areas which are geographically similar in terms of temperature, precipitation, humidity, and type of soil. A group of farmers identify a peer who is considered to use the best available methods. That farmer serves as a technical assistance agent and provides an indicator reference plot, to help other farmers reduce their risks and improve their yields. The system encourages other farmers to match the reference farmers in implementing risk reduction efforts to reduce the effects of drought, excess rains, hailstorms and frost. The objective becomes to perform or out-perform the reference plot by improving agricultural practices and reducing risk of damage from weather hazards (Hellmuth et al., 2009).

7. Role of Disaster Risk Reduction and Climate Change Adaptation Related Activities

Risk knowledge and public awareness of that risk are foundations of any risk management strategy. Insurers and public authorities can work together in increasing public awareness by collecting and providing high quality information about hazard risks and helping to translate this awareness into real action. Potential barriers and challenges include the technical difficulties related to risk assessment, dissemination of appropriate information and overcoming education and language barriers in some areas. It is important that premiums appropriately reflect the risk as otherwise this can provide a disincentive for risk reduction. The Caribbean Disaster Mitigation Project (CDMP) is an example of poor take-up while flood-risk, low-lying polder areas in The Netherlands are a positive example (Botzen et al., 2009).

Insurance solutions and the involvement of the insurance industry can contribute to the establishment of appropriate regulatory frameworks, for example through building codes and planning practices that account for relevant risks and climate change impacts. Examples are the Florida state premium discount initiative, Association of British Insurers case, Turkish Catastrophe Insurance Pool and the All India Disaster Mitigation Institute which ties micro-insurance to disaster prevention and reduction measures. Barriers to effective regulation may be a lack of good governance, institutional capacity or adequate legal and enforcement structures. Public intervention in insurance markets must also be balanced to facilitate the development of competitive markets (e.g. to keep costs down) and to ensure that insurance is allowed to be actuarially sound. The United Nations Environment Programme Finance Initiative (2009; p. 20) has proposed expanding the application of insurance mechanisms for adaptation.

8. Relationship to Key Messages

The use of insurance and financial mechanisms is part of effectively preparing for, responding to, and recovering from extreme events and disasters. Additional understanding of current and projected risks, including exposure to extreme events and increasing vulnerability is needed. Knowing and be able to project risk in order to ascertain effective financial mechanisms is part of risk transfer mechanisms. Actual or potential barriers to implementing these methods exist and there are considerable challenges constrain the effectiveness of current risk management strategies and policies.

9. Research Gaps and Needs

There are only a small number of examples as yet, of programmes that contribute to risk reduction, and use insurance tools. These do indicate that it is possible to design measures to work towards that aim but there is need for research into how to more effectively bring disaster risk reduction and insurance together, building on experience mostly from industrialised countries.

10. Summary and Conclusions

The current experience in developing countries of the benefits of insurance for in managing risks from (climate-related) natural hazards and in promoting risk reduction remains promising but limited. Insurance is growing rapidly there but it is not clear whether all programmes spontaneously achieve the benefits of reaching the most vulnerable, building resilience and reducing indirect and longer-term losses.

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Case Study 9.14. Disaster Risk Reduction Education, Training, and Public Awareness to Promote Adaptation

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1. Introduction

Disasters can be substantially reduced if people are well informed and motivated towards a culture of disaster prevention and resilience (UNISDR 2005). Disaster risk reduction education encompasses primary and secondary schooling, training courses, academic programmes, and professional trades and skills training (UNISDR 2004), community based self-assessment, public discourse involving the media, awareness campaigns, exhibits, memorials and special events (Wisner 2006). Given the broad scope of the topic, this case study identifies a few elements for effective education that can be useful in advancing adaptation. It then illustrates their implementation through practices in primary school education, training programmes and awareness-raising campaigns in various countries.

2. Overview of Education, Training, and Awareness

The Hyogo Framework calls on States to "use knowledge, innovation and education to build a culture of safety and resilience at all levels" (UNISDR 2005). States, however, report minor progress in implementation (ISDR 2009). Challenges noted include the lack of capacity among educators and trainers, difficulties in addressing needs in poor urban and rural areas, the lack of validation of methodologies and tools and little exchange of experiences. On the positive side, the 2006-2007 international disaster risk reduction campaign "Disaster Risk Reduction Begins at School",[13] furthered and raised awareness of the importance of the education agenda across some countries *(*ISDR 2009).

[INSERT FOOTNOTE 13 HERE: The 2006-2007 international disaster risk reduction campaign 'Disaster Risk Reduction Begins at School at: http://www.unisdr.org/eng/public_aware/world_camp/2006-2007/wdrc-2006-2007.htm]

2.1. Eliciting behavioural change that reduces risk

The goal of disaster risk reduction education, whether formal or informal, is ultimately behavioural change. The factors that promote this change include both *perception* and *knowledge* of risk (Paton 2005, Shaw et al 2004, Johnston et al 1999, Bonifacio et al 2010). Risk perception is shaped by psychological, social, cultural, institutional and political processes, which must be understood and accommodated for effective behavioral change (Paton 2005). In addition to risk perception, risk preparedness is shaped by amount of relevant information, level of past damages, salience of hazard and level of knowledge about the threat (Johnston et al 1999). Effective risk reduction education moves the individual from knowledge of the hazard and the risk posed to perception of the risk at individual, family and community levels, to willingness to take action to reduce risk (Shaw et al 2004). Behavioural change can be effected by undergoing the following processes: attention, comprehension, interpretation, confirmation, acceptance and retention (Enders in Shaw et al 2004).

Understanding risk perception enables the development of more effective education efforts. When faced with disaster risk information, people may overestimate existing knowledge, overestimate the effectiveness of risk-mitigation measures, or attribute the need for preparedness to others, all of which results in people underestimating risk (Paton 2005). The use of distressing images in risk communication messages can reinforce people's belief that disasters are too catastrophic for personal action to be effective (Keinan, Sadeh and Rosen 2003; Lopes 1992; Paton and Johnston in press), reducing their outcome expectancy. This belief reflects people's perception of disaster loss as being caused by uncontrollable, catastrophic natural forces (Paton 2005). Conversely, individuals or organisations infer from their ability to cope with a minor impact the ability to cope with any future occurrence or assume that future events will not exercise an adverse effect on them. Consequently they may not undertake necessary risk reduction and preparedness actions (Johnston et al).

Risk education efforts can be designed to counter these perceptions and elicit risk reduction behaviour. Two important elements are to personalize hazard information and to disseminate it in ways that engage people in debate about the personal consequences that hazards might have for them; this approach is much more effective than disseminating general risk information (Paton 2005). General information (e.g. pamphlets, media advertisements) represents a passive form of communication that fails to address the diversity of needs and expectations within a community (Ballantyne et al. 2000 in Paton 2005). To change the perception that disaster is unavoidable, risk communication efforts can present scenarios that demonstrate that hazard intensity and its impacts are unevenly distributed and that the level of damage to be expected is a function of the interaction between choices people can make to reduce risk (such as storm proofing their houses) and the hazard (Paton 2005). Thus, education should seek to convey an understanding of the natural and environmental conditions and the human actions and inaction that lead to disaster to stimulate changes in individual and group behaviour (Bonifacio et al. 2010).

2.2. Effectively communicating risk information

Based on experience of public education campaigns for disaster risk reduction, some working axioms have been demonstrated (Ross *et al*. (1991), Paton *et al*. (2005), and McClure (2006) in Bonifacio et al. 2010):

1) People need to understand who is at risk, the potential and likely physical, economic, communal and cultural heritage losses, within a specific timeframe.
2) When people are clearly informed about what they can do to reduce their risks, before, during and after a disaster, they are quite capable of understanding and remembering the basics.
3) When people are convinced that their actions will make a difference, and that they have the skills needed to reduce vulnerability, they are more likely to act.
4) Most people are motivated more by positive examples than by fear.
5) Culture is shaped by language, stories and traditions. Therefore, local knowledge can be used to transmit information.
6) Children can be engaged in active, inquiry-oriented learning through exploration and play.
7) Lectures, sermons and moral exhortations are not as effective as when people participate in a solution, when they believe it is their own idea.

3. Disaster Risk Reduction in School Curriculum

To personalize information and elicit behavioural change as described above, risk reduction programmes in schools would ideally “impart knowledge of the natural hazards themselves but also involve students in inspecting the school buildings, going outside to map the surroundings, venturing beyond to interview elders about extreme natural events in the past. Such learning could be done in ways that reinforce basic skills in listening, writing and reporting, mapping. It could integrate or be integrated into the study of history, geography, and natural science (Wisner 2006). Thus, disaster education should not be confined within the school itself, but shall be promoted to family and community (Shaw *et al*., 2004). Lectures can create knowledge, particularly if presented with visual aids and followed up with conversation with other students. Yet it is family, community and self learning, coupled with school education, which can transform knowledge into behavioural change (Shaw et al 2004).

Countries are increasingly incorporating disaster risk reduction in the curriculum (ISDR 2009). The following programme in the Philippines brings together disaster risk reduction and climate change education.

3.1. Integrating disaster risk reduction and climate change in the curriculum

The Asian Disaster Preparedness Centre (ADPC) and UN Development Programme (UNDP), with the National Disaster Coordinating Council and support from ECHO, assisted the Ministry of Education in Philippines, Cambodia and Lao PDR to integrate disaster risk reduction into the secondary school curriculum. Each country team developed its own draft module, adapting it to local needs. The Philippines added climate change and volcanic hazards into its disaster risk reduction curriculum. The relevant lessons addressed “what is climate change, what is its impact, and how you can reduce climate change impact." Other lessons focus on the climate system, typhoons, heat waves, landslides, among other related topics (ADPC 2008).

The Philippines' final disaster risk reduction module was integrated into 12 lessons in science and 16 lessons in social studies of first year of secondary school (Grade 7). Each lesson includes group activities, questions to be asked to the students, the topics that the teacher should cover in the lecture, a learning activity in which students apply knowledge gained and methodology for evaluation of learning by the students (ADPC 2008).

Under this project, 1020 students, including 548 girls, were taught the disaster risk reduction and climate change module. 23 teachers participated in the four-day orientation session. An additional 75 teachers and personnel were trained to train others and replicate the experience across the country (ADPC 2008).

4. Training

In order to effectively include disaster risk reduction and adaptation in the curriculum, teachers require (initial and in-service) training on the substantive matter as well as the pedagogical tools (hands-on, experiential learning) to elicit change (Wisner 2006, Shiwaku et al 2006).

Education programme proponents might have to overcome teachers' resistance to incorporate yet another topic into overburdened curricula. To enlist teachers' cooperation partnership with the ministry of education and school principals can be helpful (UNISDR 2007, World Bank 2009). The following programme in Indonesia and the evaluation results from Nepal demonstrate the importance of engaging teachers for effective education.

The subsequent example from Nepal, Pakistan and India focuses on training builders through extensive hands-on components in which new techniques are demonstrated and participants practice these techniques under expert guidance (World Bank 2009).

4.1. Teacher training in Indonesia

The Disaster Awareness in Primary Schools project was launched in Indonesia in 2005 with German support and is ongoing. By 2007 through this project, 2200 school teachers had received disaster risk reduction training. Project implementers found that existing teaching methods were not conducive to active learning. Students listened to teacher presentations, recited facts committed to memory and were not encouraged to understand concepts and processes. The training took teachers' capabilities into account by emphasizing the importance of clarity and perseverance in delivering lessons so as to avoid passing on faulty life-threatening information (such as on evacuation routes). Scientific language was avoided and visual aids and activities encouraged. Teachers were asked to take careful notes and to participate in practical activities such as first-aid courses, thus modeling proactive learning. Continuity with the teachers' traditional teaching methods was maintained by writing training modules in narrative form and following the established lesson plan model. Moreover, to avoid further burdening teachers' heavy lessons requirements and schedules, the modules were designed to be integrated into many subjects, such as language and physical education, and to require minimum preparation (UNISDR 2007).

4.2. Evaluation of teacher training in Nepal

A survey of 130 teachers in 40 schools in Nepal revealed that disaster risk education depended on the awareness of individual teachers. Teaching focused on the effects of disasters that the teachers could relate to from personal experience. The study concluded that teacher training is the most important step to improve disaster risk education in Nepal. Eighty percent of social studies teachers reported a need for teacher training but the study recommends that training programs should be designed to integrate DRR into any subject rather than taught in special classes (Shiwaku et al 2006).

4.3. Training of builders in Nepal, India, and Philippines

The National Society for Earthquake Technology (NSET) in Nepal conducted large-scale training for masons, carpenters, bar benders and construction supervisors over a five-month period to train them on risk-resilient construction practices and materials. Participants from Kathmandu and five other municipalities formed working groups to train other professionals. As the project was successful, a mason-exchange program was designed with the Indian nongovernmental organization SEEDS. Nepali masons were sent to Gujarat, India, to mentor local masons in the theory and practice of safer construction. Also in India, the government of Uttar Pradesh trained two junior engineers of the rural engineering service in each district to carry out supervisory inspection functions and delegated the construction management to schools principals and village education committees. Similarly, the Department of Education of Philippines mandated principals to take charge of the management of the repair and or construction of typhoon-resistant classrooms. Assessment, design and inspection functions are provided by the Department's engineers, who also assist with auditing procurement (World Bank 2009).

5. Public Awareness Campaigns

In addition to the insights on the psychological and sociological aspects of risk perception, risk reduction education has benefitted from lessons in social marketing. These include: Involving the community and customizing for audiences using cultural indicators to create ownership; incorporating local community perspectives and aggressively involving community leaders; enabling two-way communications and speaking with one voice on messages (particularly if partners are involved); and evaluating and measuring performance (Frew 2002). The following examples from Brazil, Japan and the Kashmir region illustrate good practice in raising awareness for risk reduction.

5.1. Public awareness initiative: Santa Catarina, Brazil

Between 2007 and 2009, the Santa Catarina State Civil Defence Department with the support of the Executive Secretariat and the state university undertook an initiative in this southern Brazilian state to reduce social vulnerability to disasters induced by natural phenomena and human action (SCSCDD 2008a,b).

During the two-year initiative, 2000 educational kits were distributed free of charge to 1324 primary schools. Students also participated in a competition of drawings and slogans that was made into a 2010 calendar. As the project's goal was public awareness of risk, the project jointly launched a communications network in partnership with media and social networks to promote better dissemination of risk and disasters (SCSCDD 2008a,b).

The initiative also focused on the most vulnerable populations. A pilot project for 16 communities precariously perched on a hill prone to landslides featured a 44-hour course on risk reduction. Community participants elaborated risk maps and reduction strategies. Shortly into the course, heavy rains battered the state triggering a state of emergency. 10 houses in the pilot project area had to be removed and over 50 remain at risk. Participants were surprised how quickly they had to put to use their risk reduction knowledge. Their risk reduction plans highlight the removal of garbage and large rocks as well as the building of barriers. The plans identified public entities for partnership and costs for services required. The training closed with a workshop on climate change and with the community leaders' presentation of the major risk reduction lessons learned (SCSCDD 2008d).

On international disaster risk reduction day, representatives of the community, Civil Defence and other public entities, visited the most at-risk areas of the hill community, planted trees, installed signs pointing out risky areas and practices, distributed educational pamphlets and discussed risk. One of the topics of discussion was improper refuse disposal and the consequent blocking of drains, causing flooding (SCSCDD 2008c).

5.2. Public awareness campaign in Saijo, Japan

In 2004, Saijo City in the Ehime Prefecture of Shikoku Island was hit by record typhoons that led to flooding in its urban areas and landslides in the mountains. A small city with semi-rural mountainous areas, Saijo City faces unique challenges in disaster risk reduction. First, Japan's aging population represents a particular problem. Young able-bodied people are very important to community systems of mutual aid and emergency preparedness. And as young people tend to move away to bigger cities, smaller towns in Japan have an even older population than the already imbalanced national average. Second, smaller cities like Saijo City are often spread over a mix of geographic terrains – an urban plain, semi-rural and isolated villages on hills and mountains, and a coastal area (Yoshida et. al, UNISDR 2010).

To meet both of these challenges, the Saijo City Government launched in 2005 a risk awareness programme targeting schoolchildren. Focusing on different physical environments of the city, from the mountainside to the town, the 'mountain-watching' and 'town-watching' project takes 12-year olds, accompanied by teachers, local residents, forest workers and municipal officials, on risk education field trips. The young urban dwellers meet with the elderly in the mountains to learn together about the risks Saijo City faces and to remember the lessons learned from the 2004 typhoons. Additionally, a 'mountain and town watching' handbook has been developed, a teachers' association for disaster education was formed, a kids' disaster prevention club started, and a disaster prevention forum for children was set up (Yoshida et. al, UNISDR 2010).

The programme was conceived and implemented by the city government and is an example of a local government leading a multi-stakeholder and community-based disaster risk awareness initiative that can then become self-sustaining. The government supported the programme through providing professionals from disaster reduction and education departments, funding the town and mountain watching, and putting on an annual forum (UNISDR 2010).

5.3. Public awareness campaign: DRR and climate change education in Himalayas

CEE Himalaya is undertaking a disaster risk reduction campaign in 2,000 schools and 50 Kashmir villages. In the schools, teachers and students are involved in vulnerability and risk mapping through rapid visual risk assessment and in preparing a disaster management plan for their school. Disaster response teams formed in selected schools have been trained in life-saving skills and safe evacuation (CEE Himalayas 2010).

CEE Himalaya celebrated International Mountain Day 2009 with educators by conducting a week-long series of events on climate change adaptation and disaster risk reduction. About 150 participants including teachers and officials of the Department of Education, Ganderbal, participated in these events (CEE Himalayas 2010).

Participants worked together to identify climate change impacts in the local context, particularly in terms of water availability, variation in micro-climate, impact on agriculture/horticulture and other livelihoods, and vulnerability to natural disasters. The concept of School Disaster Management Plans (SDMP) was introduced. Participants got a hands-on opportunity to prepare SDMPs for their schools through group exercises, and discussed their opinions about village contingency plans (CEE Himalayas 2010).

Some of the observations on impacts of climate change in the area discussed by participants included the melting, shrinking and even disappearance for some glaciers, drying up of several wetlands and perennial springs. Heavy deforestation, decline and extinction of wildlife, heavy soil erosion, siltation of water bodies, fall in crop yields, reduced availability of fodder and other non- timber forest produce were some of the other related issues discussed (CEE Himalayas 2010).

Participants watched documentaries about climate change and played the Urdu version of "Riskland; Let's Learn to Prevent Disasters". They received educational kits on disaster risk reduction and on climate change, translated and adapted for Kashmir (CEE Himalayas 2010).

6. Relationship to Key Messages

This case study supports the messages that improving current risk management can facilitate adaptation to climate change, and that there are unrealized opportunities for synergies between disaster risk reduction and climate change adaptation. As shown above, there is abundant experience in educating, training and awareness raising to reduce disaster risk. Knowledge of the psychological and sociological factors that influence risk perception would also likely apply to climate change impacts; hence, climate change education programmes could use this knowledge in programme design. Likewise knowledge of effective risk-communication techniques and the elements for behaviour-changing education can be immediately utilized for adaptation education. Finally, the initiatives undertaken around the world, including those described here, could easily include climate change information to deliver robust education on climate and nonclimate risks.

7. Research Gaps

Education programmes, training initiatives and awareness campaigns are rarely empirically assessed for their effectiveness in changing behaviour for risk reduction (with exceptions such as the evaluation by Shiwaku et al 2006 of Nepalese DRR education). Good practices worldwide are documented in publications aiming to foster replication of activities in other locales; however, success is evaluated on the basis of the number of output activities achieved or students reached. Future research should evaluate the effectiveness of programmes in qualitative terms to then identify the elements of those programmes that make them most effective for target audiences. In addition, it would be useful to learn whether disaster risk perception differs significantly to climate change impact risk perception. The outcome of such research would assist in better targeting education initiatives.

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Case Study 9.15. Multi-Level Institutional Governance

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1. Description of Thematic Approach

Southeastern Spain has a semi-arid Mediterranean climate and experiences droughts that put stress on irrigated agriculture, the region's most important economic sector. According to the IPCC's Fourth Assessment Report, the Iberian Peninsula is one of the regions most prone to an increased drought risk and irrigation water demand because Mediterranean droughts are expected to start earlier in the year and last longer (Alcamo et al., 2007).

The Segura River Basin in southeastern Spain experienced a severe drought from 2005-2010, the region's second drought in the last two decades. Due to successful drought risk management by local authorities, the 2005-2010 drought has had a smaller impact on the region's agricultural production than the previous drought even though it was both longer and more severe: in the first year after the onset of drought (2005-2006), agricultural yields fell by 2.1 percent compared to a decline of 7.1 percent experienced in 1993-1994. The local authorities were able to meet the additional demand for irrigation by:

- Increasing the use of recycled water
- Reducing water loss and urban water demand
- Purchasing water rights from individual owners
- Transferring water from another river
- Desalinizing seawater
- Supplementing water supply by digging drought wells.

The European Commission's Water Framework Directive (2000) delegates drought risk management to member states, and in 2001 Spain enacted legislation to implement this directive and to decentralize drought risk management even further by making it the responsibility of river basin districts and local governments (Spain, 2001). Spain's National Drought Plan was the culmination of fifteen years of groundwork and planning (Spain, 2001), and in the case of the Segura River Basin the federal government delegated the responsibility for drought risk management to a local agency with nearly 70 years of experience managing drought risk. This devolution of authority is based upon the "subsidiary" principle, which allocates responsibilities for policy development and implementation to the lowest level of government that can meet a given policy's objectives (Inman and Rubinfeld, 1998). Through the EC Water Framework Directive, the local authorities in the Segura River Basin are supported a network of experts from the EU. At the federal level the Government of Spain supported this process of decentralization through a royal decree that gave the local water boards the authority and resources to implement emergency policies, and which established a multi-level institutional framework connecting the individual water boards with one another and with the Ministry of the Environment (Spain, 2005).

2. Description of Multi-Level Institutional Governance and its Relation to Hazardous Events

Most extreme risks are managed centrally; yet, a broad range of research reflects that decentralization is critical to effective responses. Therefore, a tension exists between devolution or centralization of the extreme risks of climate change. While on the one hand centralization is necessary to overcome compartmentalization (Wisner 2003), ad hoc decision-making, and the concretization of localized power relations (Naess et al. 2004), devolution is critical because it results in more accountable, credible, and democratic decision-making. These decisions about governance approaches are critical because they shape efficiency, effectiveness, equity, and legitimacy of responses (Adger 2003). In addition, motivation for management at a particular scale promises to influence how well extreme impacts are managed, and therefore affect disaster outcomes (Tsing et al., 1999). Finally, decisions made at one scale may have unintended consequences for another (Brooks and Adger 2005), meaning that governance decisions will have ramifications across scale and contexts. In all cases, the selection of a framework for governance of extreme impacts may be issue or context-specific (Sabatier 1986).

Current management practices have tended to be centralized at the federal level. This may be, in part, due to the ways in which many climate extremes affect environmental systems that cross political boundaries resulting in scale discordance if solely locally managed (Cash and Moser 2000), or because human reactions cross local boundaries, such as migration that in response to extreme events, necessitating national planning (Luterbacher 2004). In addition, in situations where civil society is flattened due to poverty, marginalization, or historical political repression, regional and federal governments with access to resources may be most important in instigating public action (Thomalla et al. 2006). National-level policies can facilitate otherwise impossible localized strategies through the establishment of resources or legal frameworks (Adger 2001) and often shape what localities can accomplish within existing governance frameworks (Keskitalo 2009).

Yet, centralized approaches have faced many challenges. Disaster preparedness in Less Developed Countries (LDCs), which has often been centralized and focused on a particular risk rather than a holistic approach, has been unable to advance capacity at the grassroots level (O'Brien et al. 2006). For example, national adaptation efforts in Southern Africa have been insufficiently integrated into local strategies, resulting in resilience gaps (Stringer et al. 2009). Challenges regarding credibility, stability, accountability, and inclusiveness are some of the critical issues that plague efforts at the national level (Bierman 2006). The private sector has begun to engage in financial assistance for climate change impacts through insurance for developing nations that have limited supplies to assist impacted households (Hoeppe and Gurenko 2006). However, it is not yet clear how effectively such funding can be distributed to households themselves. Devolution of management is supported by the need to overcome these challenges.

As a general rule, actions generated within and managed by communities are most effective since they are context-specific and tailored to local environments (Cutter 2003; Liso et al. 2003; Mortimer and Adams 2001). Bottom-up management of climate risks acknowledges that the vulnerable live within countries, and are not nations themselves (Kate 2000). Involvement of local or grassroots groups in the planning and implementation of preparedness plans can lead to greater resilience (Larsen and Gunnarsson-Östling 2009). For example, communities themselves can lead vulnerability assessments as a part of community-based adaptation (Yamin et al. 2005). Communities can also be effectively engaged in information dissemination and training, awareness raising, accessing local knowledge or resources, and mobilizing local people (Allen, 2006). Local management may need assistance from non-traditional sources. The private sector can facilitate action through the provision of resources, technology, and tools, such as insurance against the extreme impacts of climate change to support (Linnerooth-Bayer et al. 2005). Such programs could introduce preventive measures, such as retrofitting buildings and public education.

Since environmental systems relate to risks for local population and since environmental management functions across scales (Berkes 2002), the creation of effective multi-level governance and management systems that span these scales are critical in responses to extreme impacts (Adger et al. 2005; Olsson and Fulke 2001). Devolution of activities for climate change threat reduction can also be managed by cities that develop plans for multiple communities, such as that in Dhaka, Bangladesh where urban-level plans have advanced community resilience (Roy 2009). Such city-level plans can be communalized through the incorporation of participatory approaches (Laukkonen 2009). When necessary, localized plans should be supported by the integration of multiple levels of management, although questions about how to scale up from localized assessments to national-level plans still remain (van Aalst et al. 2008).

3. Analysis of Information Available on Multi-Level Institutional Governance in Specific Cases

3.1. Drought risk management in the United States

Drought risk management is also decentralized in the United States, with authority resting with state governors. As opposed to the example above from the EU, in which responsibility devolved intentionally, drought risk management in the U.S. was decentralized despite an effort from several states, federal agencies, and research institutes to pass a proposed law creating a national drought risk management plan in 2000. As a result, responsibility for drought risk mitigation and response remains with individual states, many of whom have adopted drought contingency plans.

Drought risk reduction activities vary from one state to another due to the diverse regional differences, the unique institutional arrangements, differences in drought impacts, and the wide range of agencies involved (Wilhite 1997; Wilhite and Vanyarkho, 2000). Nebraska's drought risk mitigation plan is well regarded for its comprehensiveness, and a number of its actions have been extremely successful at reducing drought impacts on agricultural production (Hayes et al. 2004). Nebraska's plan was adopted in 2000 and is a revision of the state's previous programme. To create the current plan, officials spent two years consulting with stakeholders from federal, state, and local agencies, as well as tribal governments, the private sector, and individuals (Hayes et al., 2004). More importantly, this new plan links agencies at every level of government and assigns each with potential actions, and experts have worked closely with farmers and provided workshops and trainings around the state for vulnerable communities (Hayes et al., 2004).

3.2. Multi-level flood risk reduction in France

In 2007, the European Commission endorsed a flood risk directive that, like its Water Framework Directive, is based on the subsidiarity principle and which calls upon each of its Member States to assess, map, and prepare for flood risk within their country (EC, 2007). By this time, the French Government had already established general framework for coastal flood risks at the sub-national and local level. This framework for decentralized flood risk management was developed with input from all levels of government, and this process is being reinforced through legislation (The Grenelle of the Environment) and financing by the Barrier Fund for natural risk prevention, which is in turn funded by obligatory contributions based on the *CatNat* insurance premiums (Deboudt, 2010). The decentralization process has been strengthened by legislation (the Bachelot Law) that requires:

- The dissemination of guidance material and decision-support tools
- Local capacity development
- Multi-level, integrated coastal zone management policies for the French littoral
- Development of Predictable Natural Risk Prevention Plans through multi-stakeholder dialogues
- Clearly defined responsibilities for implementation (France 2003; Deboudt, 2010).

The decentralization of flood risk management has been adopted by many different countries, in principle, but the institutional arrangements vary significantly due to differences in public awareness, the degree of civil society and private sector participation, the institutional inertia of precursor regimes, and the transaction costs of changing to new arrangements (Meijerink and Dicke, 2008).

3.3. Chile

Dryland communities in Chile have created local committees to manage extreme events when national and regional level institutions did not effectively communicate or collaborate with them (Young et al. 2010).

3.5. Cayman Islands

The Cayman Islands responses to Hurricane Ivan in 2004 after three prior events, Gilbert, Mitch, and 2000 Michelle, demonstrated that adaptation planning at community and national levels was necessary to improve preparedness and resilience (Adger et al. 2005). These measures included improving localized social cohesion and diversifying adaptation strategies (Tompkins 2005).

4. Research Gaps and Needs

Biesbroek et al. (2010) identified the following gaps including, but not limited to: research scaled to meet local, subnational, and national policy needs; research on the roles of institutions and on the mechanisms and responsibilities involved in multi-level governance of disaster risk reduction and adaptation; research comparing sectoral and cross-sectoral measures; research on different policy instruments and frameworks for evaluating adaptation policies.

Downscaled climate models and disaster loss data are needed to develop locally scaled risk assessments and adaptation plans. And more research is needed to determine the optimal scale and institutional balance for dealing with hazards. There are numerous papers analyzing the decentralization of drought and flood risk management, but more research is needed for multi-institutional management of other climate hazards, such as cyclones.

More research is needed on the enabling environment for effective decentralization of disaster risk reduction and climate change adaptation planning. Considering the management of environmental hazards, Karlsson (2007) found that stakeholders' value systems would need to be shifted to a more selfless global concern in order for effective multi-level governance to be possible. Numerous other analyses of decentralization in a variety of locations and contexts (Ribot, 1999; Lane et al., 2004; Oyono, 2005; Meijerink and Dicke, 2008) support these findings and reveal that decentralization and multi-level governance have, in some cases, institutionalized conflicts between local stakeholders and unintentionally reinforced the hegemony of local elites.

Studies of the enabling environment also need to consider institutional inertia and policy resistance. Mexico has adopted a decentralized approach to disaster risk reduction, but Arellano-Gault and Vera Cortés (2005) have found that the Civil Protection National System (CPNS) still functions in a very centralized, top-down manner because the devolution of political authority was not accompanied by comparable decentralization of financial or administrative capacity. Disaster preparedness/response budgeting is still highly centralized; the armed forces, which are nominally responsible for playing only a coordinating role, instead impose military rules and decision-making structures on everyone else, and once deployed they act as the final arbiter and enforcer (Arellano-Gault and Vera-Cortés 2005). In the same vein, an OECD review (2004) found that decentralization of poverty eradication has had little discernable impacts on poverty levels, and a separate analysis of decentralization in 19 countries also found that where state capacity is lacking, decentralization of poverty eradication programmes can even increase rural poverty (Jütting et al. 2004).

5. Summary and Conclusions

Adaptation to the impacts of climate change, such as increased exposure to climate extremes, is a challenge at administrative, temporal, and spatial scales (Adger et al., 2005; Urwin and Jordan, 2008). It requires the involvement of a variety of stakeholders from the public and private sectors and civil society, and there is a growing recognition that successful adaptation practices require the integration of strategies across sectors and within multiple scales of governance in a coordinated manner (Biesbroek et al., 2009; Biesbroek et al., 2010; Gopalakrishnan and Okada, 2007). Effective decentralization and multi-level governance of disaster risk reduction must be accompanied by transfer of capacity and resources to newly accountable local actors, and parallel support is needed for civil society organizations that hold local governments accountable and fill the void when those governments fail (Mitchell et al., 2008). Examples of this type of formal coordination include National Adaptation Strategies and National Platforms for Disaster Risk Reduction.

Procedural dimensions, such as participatory models, that allow for involvement for a wider range of local stakeholders provide a mechanism to mitigate existing power dynamics that might otherwise be concretized in localized planning (Paavola and Adger 2002; Oyono 2005). If multiple levels of planning are to be implemented, mechanisms for facilitation and guidance on the local level are needed to ensure that procedural justice is guaranteed during the implementation of national policies (Thomas and Twyman 2005).

The decentralization of disaster risk reduction and climate change adaptation must be complemented with increased autonomy of local agencies and enhanced support of these actors from national governments and regional institutions, such as the EU (Baker and Refsgaard, 2007; Gopalakrishnan and Okada 2007). Taking these ideas into account might allow national governments to help facilitate programs where local community members jointly engage in risk management (Perez et al.1999). Such programs may allow for an integration of bottom-up and top-down approaches that overcomes each approach's strengths and weaknesses (Urwin and Jordan 2008).

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Case Study 9.16. Disaster risk reduction legislation as a basis for effective adaptation

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1. Introduction

Governments will need to assess in the short term whether existing national legislation to reduce and manage disaster risk is adequate for adapting to climate change. A majority of States have some form of disaster risk management legislation or are in the process of enacting it (UNISDR 2005, UNDP 2007). This case study examines framework legislation in South Africa, Colombia and the Philippines and identifies elements that may be useful in strengthening legislation by integrating climate change provisions into existing disaster risk management law or in developing stand-alone climate change adaptation legislation.

2. Status of Disaster Risk Management Legislation Worldwide

In their reports on implementation of the Hyogo Framework, Governments reported that, between 2005 and 2009, good progress had been made in strengthening disaster risk management legislation to address deficiencies in disaster preparedness and response (ISDR 2009). The majority of this legislation was drafted or reformed since the mid-1990s, falling within the UN International Decade for Natural Disaster Reduction (1990–1999) and the subsequent International Strategy for Disaster Reduction (from 2000 onwards) (Pelling and Holloway 2006; UNDP 2007). Policies and legal frameworks addressing disaster risk generally exist in each sector in high- and middle-income States (ISDR 2009); however, many low-income States, particularly in Africa, report a lack of adequate financial, human and technical resources as the major reason for underachievement concerning effective legislative systems. In addition, while many States report the existence of sector policies and legal instruments, national-level policy and legislation on disaster risk reduction remains weak (ISDR 2009). Moreover, burgeoning national legislation for *disaster management* does not necessarily include a *disaster risk reduction* orientation (Pelling and Holloway 2006). However, in keeping with the global paradigm shift from disaster response to prevention (Britton 2006, Benson 2009), countries such as South Africa, Colombia and the Philippines are reviewing and adapting their risk management laws to a reflect a more preventive focus. Key elements of these norms, and the processes to develop the laws, are here reviewed.

3. Pre-Conditions for the Development of Effective Legislation

A comparison of different country experiences shows that legislative changes often take years to succeed and require transformative and sustained energy and engagement, which is often triggered by major disasters or political shifts, the engagement of particularly dynamic individuals, a well-educated population and citizen participation in a decentralized environment (UNDP 2007).

Advocates of the Disaster Management Act and Framework in South Africa persevered over eleven years to develop a comprehensive disaster risk reduction and risk management law now internationally reputed for its emphasis on prevention and its comprehensive approach to disaster risk reduction. Galvanized by devastating floods and droughts, and the country's high motivation for change in the post-Apartheid era, the first steps undertaken were public consultation on a green and white paper on disaster management. Challenges included inconsistent public consultation in the drafting and the exclusion of local authorities; insufficient interdisciplinary engagement; and limited executive authority to promote interdepartmental integration (Pelling and Holloway 2006). The will to complete the Act and Framework in South Africa was stimulated by public concern about worsening disasters that stirred political interest, skilled political leadership that championed the cause, continuous commitment by highly capable disaster risk reduction professionals, and local professional interest in aligning South African legislation with international frameworks (Pelling and Holloway 2006). The process led to the passing of three disaster management bills and the promulgation in 2003 of the Disaster Management Act No. 57 of 2002 and of the National Disaster Management Framework in 2005 (SANDMC 2006; Pelling and Holloway 2006).

The Philippines' experience is similar. Reflecting the international paradigm shift in emphasis from a disaster management to a disaster *risk* management approach and as a result of rising concern about increasing disasters in the country (Benson 2009), dozens of bills were submitted to Congress over the last ten years with the aim of changing the primarily reactive 1978 disaster management legislation to a more pro-active, preventive law (Benson 2009, Britton 2006, World Bank 2004). However, it was only in 2009 that new disaster risk management legislation was passed, the Disaster Risk Reduction and Management Act 10121. Progress in passing a bill was stymied in part by lack of coordination among the many, often conflicting bills, as well as additional submissions for piecemeal change around specific issues (Benson 2009). As in South Africa, a number of individuals and focus groups, such as senators and other parliamentarians (Benson 2009), Philippine specialists and international consultants (Britton 2006) were crucial for success.

Though skilled, high-level political champions can provide needed impetus for building commitment to disaster risk reduction and for mainstreaming it into development, political champions of disaster risk reduction are rare (Benson 2009). Even in the Philippines, the Climate Change Act 9729 of 2009 was enacted after only 2 years of consideration by the Fourteenth Congress, in contrast with the frustrating decade invested in trying to modernize disaster risk management law, which reflects the higher political interest generated by climate change (Benson 2009).

4. Key Elements of Comprehensive Disaster Risk Reduction Legislation

4.1. A legal framework for risk reduction

Although some countries successfully implement disaster risk reduction through a number of sectoral laws, such as Sweden[14] and Slovenia[15], an overarching, comprehensive legal framework is considered a requisite for the effective implementation of disaster risk reduction (ISDR 2009, UNDP 2007). Most importantly, an overarching framework can help in striking the balance between a multitude of sometimes contradictory laws and decrees, such as 20,000 legal acts in Kyrgyzstan (UNDP 2007), or over 120 different pieces of disaster risk management related legislation in Indonesia (UNDP 2009).[16]

[INSERT FOOTNOTE 14 HERE: e.g. The Seveso Act, The Environmental Code; The Planning and Building Act, The Land Code, the Water Directive, The Flooding Directive, And The Civil Protection Act]

[INSERT FOOTNOTE 15 HERE: e.g. The Protection Against Natural • and Other Disasters Act 3535 Official Gazette of the Republic of Slovenia, 64/94, 51/2006., The Fire Protection Act 3636 Official Gazette of the Republic of Slovenia, 71/93, 3/2007, The Fire Service Act 3737 Official Gazette of the Republic of Slovenia, 1993, 2005, The Slovenian Red Cross Act 3838 Official Gazette of the Republic of Slovenia, 7/93, The Recovery from the Consequences of Natural Disasters Act 3939 Official Gazette of the Republic of Slovenia, 75/2003, The Protection against Drowning Act 4040 Official Gazette of the Republic of Slovenia, 42/2007]

[INSERT FOOTNOTE 16 HERE: The latter was addressed in the 2007 Disaster Management Bill that aims to provide leadership for comprehensive disaster risk reduction (UNDP ILS Indonesia 2009).]

Effective disaster risk management legislation "draws a line" around the minimum acceptable level of action and responsibility; it enables actors and agencies to take calculated risks and initiate needed action. Moreover, without comprehensive and binding laws, essential tasks will not be undertaken and the status quo will be maintained (Britton 2006). The law can be used to provide penalties and incentives by enforcing standards, to empower existing agencies or establish new bodies with new responsibilities, and to assign budget lines (Pelling and Holloway 2006).

In South Africa, the 2002 Disaster Management Act provides such a comprehensive framework for disaster risk reduction implementation at all levels, and explicitly avoids subsuming disaster risk reduction within the disaster management paradigm (Pelling and Holloway, 2006)**.** The South African Act defines the structure that governs disaster risk management in the country through a hierarchical disaster management structure including a cabinet committee at the apex; an advisory forum with representatives from national and provincial departments, local government, business and civil society; as well as disaster management centres at national, provincial, metro and district levels. It also establishes disaster management frameworks for all levels of government with clear roles and responsibilities, mandates the development of disaster management plans for each government level and the creation of a national disaster management information system (SANDMC 2007).

Similarly, Colombia has framework legislation that organizes disaster risk management in the country at all levels of government. Yet Colombia has also enacted dozens of sector-specific laws that govern and support disaster risk reduction (Vásquez 2006, Ministerio 2009). Colombia's framework legislation, Law 46 of 1988 and Decree 919 of 1989, created the National System for Prevention and Response to Disasters, the SNPAD, for its Spanish-language acronym, which is supported by a national plan that establishes a holistic policy within the framework of sustainable development planning and implementation (Cardona and Yamín 2007). The SNPAD created committees at all levels of government with defined roles and responsibilities, taking an approach that is systemic, participatory and decentralized. This approach has been supported by a number of norms in the 1990s in other sectors, in particular environment, land use, housing and urban development, and education, among others (Vásquez 2006).

4.2. Positioning of DRR legislation

A factor that affects the political authority of the national disaster risk management body is its positioning in relationship to the highest level of government (UNDMTP 1998, UNDP 2007, ISDR 2009). National disaster risk management offices attached to prime ministers' offices usually can take initiatives vis-à-vis line ministries, while their colleagues operating at the sub-ministerial level are likely to face administrative bottlenecks (UNDP 2007). High-level support is particularly important to enable disaster risk reduction legislation to provide a framework for strategies to build risk reduction into development and reconstruction (Pelling and Holloway 2006). Many governments delegate the establishment and coordination of institutional systems for disaster risk reduction to civil defence and protection organisations traditionally responsible for emergency response, which usually do not have the competence in development planning and regulation necessary to engage with other sectors nor the necessary political authority within government to do so (World Bank 2008).

South Africa's Intergovernmental Committee on Disaster Management is established by the president and accounts to the president through Cabinet on response once a disaster has occurred (SANDMC 2007). In Colombia, the original robust institutional structure for risk reduction was weakened through a series of reforms that have reduced its standing in the hierarchy and diminished its political power, although recently the president convened entities at all levels to motivate them to fulfill their disaster risk reduction mandates (Ministerio 2009). Bolivia and Nicaragua, hybrid versions of Colombia's disaster risk reduction structure, give maximum authority to the national committee headed by the president and including representatives from the major ministries, the national department of planning, civil defence, the Red Cross Society and private sector members (UNDP 2007).

Creating an active link to the development sphere, the South African Act mandates the development of risk management plans to form an integral part of the Integrated Development Plan (IDP) of each municipality. South Africa is among the world's few to have made a legal connection between disaster risk reduction and national development planning frameworks. Others include Comoros, Djibouti, Ethiopia, Hungary, Ivory Coast, Mauritius, Romania and Uganda (Pelling and Holloway 2006).

In the Philippines, the highest policy-making and coordinating body for disaster management, the National Disaster Coordinating Council, which was renamed National Disaster Risk Reduction and Management Council under the new Act of 2010, sits within the Department of National Defense. As such it is focused on disaster preparedness and response and does not have sustainable development and poverty reduction responsibilities. Consequently it is less effective as an advocate of mainstreaming disaster risk reduction into development (Benson 2009). However, the new Act of 2010 attempts to redress this issue by including experts from all relevant fields as members of the Council (Act 10121, Sec.5; Sec 11(2)) and expressively defining its mandate on mainstreaming disaster risk reduction into sustainable development and poverty reduction strategies, policies, plans and budgets at all levels (Act 10121, Sec. 2).

4.3. Budget allocation and adequate funding for prevention

Funding is the ultimate litmus test of government commitment to disaster risk reduction (UNDP 2007). Integration of disaster risk concerns into government budgets should be tackled from two angles, ensuring that levels of public expenditure on risk reduction are sufficient and that there are adequate financial arrangements to manage the residual risk (Benson 2009).

In South Africa, eight years after the promulgation of the Act, most district municipalities have not established the centres required by the Act and do not have disaster risk reduction plans in place (SACoGTA 2009) mainly due to a lack of resources to cover the costs of activities stipulated for funding in the Framework (SACoGTA 2009, Visser and Van Niekerk 2009). Reasons for the lack of funding include a lack of clarity of the Act on the funding sources for developing and maintaining the centres it establishes at all levels and the management plans they are to prepare (Visser and Van Niekerk 2009). Moreover, the Act and Framework do not provide adequate guidance to municipalities on funding arrangements for disaster risk reduction, response and recovery. Though the Act states specifically that the legislation must provide a framework within which organs of the state may fund disaster management, with emphasis on preventing or reducing disaster risk, it is not clear which processes should be followed by municipalities to access funding, especially when it should be provided by national or provincial government. It is also not clear to what extent municipalities should fund disaster risk management out of their own budgets (Visser and Van Niekerk 2009).

Similarly, in Colombia, more than 80 percent of municipalities are able to assign only 20 percent of their own unearmarked resources to risk reduction and disaster response. Because the law does not stipulate percentages and amounts, municipalities allocate minimal sums for disaster risk reduction (Ministerio 2009) given competing infrastructure and social spending needs (Cardona and Yamín 2007). Colombia's National Fund for Calamities lacks clear rules for capital accumulation and disbursement; its funding stems from unreliable sources and the national government has been reducing its budget allocation. As a result, SNPAD's actions are limited, and the Fund's resources are directed to emergency response rather than prevention (Cardona and Yamín 2007).

In the Philippines, the new Act 10121 renames the Local Calamity Fund as the Local Disaster Risk Reduction and Management Fund and stipulates that no less than 5 percent shall be set aside for risk management and preparedness. Thirty percent shall be allocated for quick response to disasters (Act 10121, sec 21 and 22). Further, to carry out the provisions of the Act, the Commission allocated one billion pesos or 21.5 million USD (Act 10121, Sec 23). These changes reflect lessons learned to date when disaster-related budgetary allocations were primarily intended for post-disaster response through calamity funds and were inadequate to meet response and risk reduction needs (Benson 2009).

South Africa's and Colombia's experiences are replayed around the world. Except for some high-income countries, Governments report a lack of systematic policy or institutional commitment to providing dedicated or adequate resources for disaster risk reduction, in particular in the absence of legislation that makes financial allocations legally binding (ISDR 2009). Even in countries, such as those discussed here, in which funding for disaster risk management is mandated by law, actual resource allocation for disaster risk reduction remains low and is concentrated in preparedness and response (UNDP 2007). Allocations to address the underlying risk factors by development sectors are not adequately documented and accounted for (UNDP 2007).

4.4. Public participation, information, education

Public awareness and a functioning legal system are essential to assign accountability for disaster losses and impacts (UNDP 2007). South Africa's and the Philippines' Acts have provisions for the involvement of NGOs, traditional leaders, volunteers, community members and private sector in disaster risk reduction. In line with the finding that relatively few States actively involve business despite its crucial role in effective disaster risk reduction (UNDP 2007), South Africa does not explicitly mandate the private sector to incorporate disaster risk reduction in its working processes. Some positive examples can be found in the Philippines' legislation, which includes representatives of the private sector as members of the disaster risk management council (Act 10121, Sec 5), and Indonesia's legislation which requires businesses to comply with disaster management organization policy, report to the government, transparently inform the public and support humanitarian activities financially (UNDP 2009). The Philippines' legislation gives great importance to the local level by mandating the establishment of provincial, city, and municipal disaster risk reduction and management councils, as well as local disaster risk reduction and management offices in every province, city and municipality, in addition to a *barangay* disaster risk reduction and management committee (Act 10121, Sec12(3)).

Closely connected to public participation, South Africa's Act includes mandates for capacity building, training and education, research and the inclusion of traditional knowledge. The development of these provisions aligns South Africa with internationally agreed good practice. The Hyogo Framework, which was agreed by governments after South Africa's Act was promulgated, states: "The starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and of the ways in which hazards and vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge" (UNISDR 2005).

5. Linking DRR and Adaptation in Legislation: The Philippines

When crafting climate change legislation, policymakers might chose to strengthen existing risk reduction legislation by integrating climate change provisions, thus resulting in a robust framework for reducing existing risks and adapting to those related to climate change. Alternatively, legislators might enact new, stand-alone adaptation legislation, in which case a review of the country's experience in both developing and implementing disaster risk management laws would be helpful to avoid previous pitfalls and benefit from lessons learned. The Philippines is at the forefront of this development: not only does the new disaster risk reduction legislation address climate change, the Climate Change Law of 2009 addresses disaster risk reduction. As stated above, parliamentarians, in particular the "Manila Call for Action of Parliamentarians on Disaster Risk Reduction and Climate Change Adaptation" (IPU 2009) were instrumental for the quick adoption of the law. Further political support was provided in 2010, when the Inter-Parliamentary Union adopted a resolution to inter alia, "foster the strong political will and allocate the budget funds needed to develop a national legal framework designed to ensure synergy between disaster risk reduction and climate change adaptation, and between disaster risk reduction and poverty reduction and socio-economic development, so as to protect the best interests of those vulnerable to geological and climate-related disasters" (IPU 2010).

The Philippines Climate Change Act states at the outset: "As a party to the Hyogo Framework for action, the State likewise adopts the strategic goals in order to build national and local resilience to climate related disasters…Further recognizing that climate change and disaster risk reduction are closely interrelated and effective disaster risk reduction will enhance climate change adaptive capacity, the State shall integrate disaster risk reduction into climate change programs and initiatives." (Act 9729, Sec 2). Likewise, the Philippines Disaster Risk Reduction and Management Act incorporates several linkages to climate change (Act 10121, Sec 2 (a), (d), (e), (g)).

In line with the Disaster Risk Reduction and Management Act, the Climate Change Act creates a Commission to be chaired by the President and attached to the President's Office, thus ensuring highest political support for collaborative implementation. The Commission is composed by the Secretaries of all relevant departments as well as "(h) Secretary of the Department of National Defense, in his capacity as Chair of the National Disaster Coordinating Council;" and representatives from the disaster risk reduction community. Main functions of the Commission include to "Ensure the mainstreaming of climate change, in synergy with disaster risk reduction, into the national, sectoral and local development plans and programs" (Act 9729, Sec 9 (a)) and to create a panel of technical experts, consisting of practitioners in disciplines that are related to climate change, including disaster risk reduction" (Act 9729, Sec 10).

Finally, the Act devolves substantial power to local government units and calls upon them to formulate, plan and implement climate change action plans and expressly authorizes local government units to appropriate and use funds from their internal revenue allotment. Additional funds of about 1.075 million USD are allocated for the implementation of the Act.

6. Relationship to Key Messages

This case study supports the message that improving current risk management can facilitate adaptation to climate change. As shown above, the robustness of South Africa's and Colombia's legislation and its focus on risk reduction garnered international recognition yet experience gained through implementation reveals elements that could be strengthened. Lawmakers can learn from these experiences, as Philippines aims to do with its two new laws, in particular to make clear provisions for adequate funding for implementation and responsibilities at every administrative level. Robust and flexible legislation for disaster risk reduction may not require modification for climate-smart management if, for example, such legislation harnesses local knowledge and experience, promotes strategic action including at sub-national level, as illustrated by the South African and Philippine examples. Some aspects for which climate change may require adjustments to existing legislation are to ensure the gathering of baseline/science information, promote iterative learning and respond flexibly to change. The legislation of South Africa, Colombia and the Philippines explored here support the message that climate change adaptation should take into account and learn from the evolving body of disaster risk management theory and practice, with the aim to increase resilience to extreme and non-routine events.

7. Research Gaps and Needs

Preparation of this case study revealed a dearth of analysis about existing disaster risk reduction laws and their effectiveness. Although most States have national disaster risk reduction and management laws, most of which are available online, an analytical review of the global body of disaster risk reduction laws has not been undertaken. UNDP's 11-country study (UNDP 2005) and the ISDR's Global Assessment Report (ISDR 2009) of government reports are good first steps. Nevertheless, comparative studies of particular provisions and their effectiveness across States' disaster risk reduction laws should be undertaken. For instance, comparative studies of provisions for budgetary allocation, as well as decentralized management, could yield important lessons to improve legislation for both disaster risk reduction and adaptation. It would be most useful to undertake legislative analysis to ascertain the pros and cons of the two prevalent legislative models: comprehensive disaster risk reduction legislation versus provisions for risk reduction integrated into the laws of all relevant sectors without an overarching framework. Moreover, evidence should be gathered to validate the view that the achievement of multi-sector commitment depends on disaster risk reduction being overseen and headed at the highest levels of government—a provision usually specified in the law. Finally it would be most useful to document and analyse the development, enactment and implementation of legislation for adaptation, whether governments chose to strengthen existing disaster risk management legislation or to develop new laws specifically for adaptation based on local experience reducing disaster risk. As appropriateness is likely to vary by national circumstances, studies on effectiveness of both approaches would be helpful to legislators worldwide.

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Case Study 9.17. Hard and Soft Defense in Coastal Zones Adaptation

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1. Introduction

Waves and storm surges can erode shorelines, damage dykes, and flood coastal communities, rice paddies, and aquaculture facilities. Sea level rise increases those impacts. The impacts of other extreme events on coastal zones, like tropical cyclones (typhoon or hurricane), are expected to increase because of sea level rise and changes in intensity, larger peak winds and more heavy precipitation associated with climate change. The IPCC Synthesis Report (2007) considered the mangroves, the salt marshes and the coral reefs ecosystems are *likely* to be especially affected by climate change.

2. Coastal Defenses

The coastal defenses have traditionally relied upon “hard defense” structures such as sea walls, dykes and tidal barriers. Those adaptation strategies dependent on engineering and technology can have significant high economic cost and negative impacts on biodiversity (Campbell *et al*, 2009). It was recognized in the IPCC (2007) that those structures can alter sediment deposition; prevent inland migration of vegetation in response to seal level rise and impact upon salt marshes. There will also be impacts on fisheries by impeding migration to and from the tidal flood plain. There is evidence that these structures, both through physical destruction during infrastructural development and by altering the ecological niche and salinity regime, threaten the mangrove ecosystems (Gilman *et al*, 2007 and Gilman *et al,* 2008) and impact negatively the salt marshes and dunes (Glick, *et al, 2009)*

The coastal protection adaptation strategies range from “hard defense” to “soft defense” such as natural resources management (Adger *et al* 2007). Soft engineering solutions incorporate activities such as dune and wetland restoration, planting of marsh vegetation and mangroves, and the conservation and/or sustainable management of those mentioned ecosystems, including coral reefs and sea grasses. From a practical point of view, both hard and soft defenses need to be integrated to facilitate adequate adaptation. However one element is crucial in order to strengthen ‘soft defense’ approach and to reduce over dependency on hard defense is building up of ‘resilience’ of habitant through inland infrastructure and careful land use planning. Flexibility in food security of the local population is key in succeeding with ‘soft defense’ as the economies of these populations tend to be biomass-based.

A Rich biological diversity can play an important role in the “soft coastal defense“ solutions. Coastal wetlands can absorb wave energy and reduce erosion and direct wind effect. (Day, Jr, *et al, 2007)*. Mangroves forests can provide physical protection to vulnerable coastal communities whilst providing ecosystem good and services such as productive fisheries and harvesting shellfish to the most vulnerable people (Adger *et al,* 2005, and Reid and Huq 2005). In addition coastal mangroves act as safety barriers against natural hazards such as floods, cyclones, and tsunamis although severe cyclones may destroy the mangroves themselves, while wetlands filter pollutants and serve as water recharge areas and nurseries for local fisheries (Kerr and Baird 2007; Sale et al. 2008).

3. Value of Coastal Ecosystems

In economic planning, coastal ecosystems tend to be undervalued, usually because only their direct goods and services have been included in economic calculations (e.g. forestry resources), but this represents only a minor part of their total values. A number of studies, however, support the ecological and social role of mangroves and other coastal ecosystems and the cost-effective benefits of restore and conserve them. The Red Cross of Viet Nam (IFRC, 2002) began planting and protecting mangroves with support from the World Bank under the leadership of the Vietnamese national and provincial governments. Restored mangroves have been demonstrated to attenuate the height of waves hitting the shore, and to protect properties and people life from damaging cyclone Wukong in 2000 and the severe storm events in 2005 and 2006. Nearly 12,000 hectares of mangroves were planted in Viet Nam at a cost of US$ 1.1 million. These investments saved an estimated $7.3 million per year in dyke maintenance whilst providing protection against a typhoon that devastated neighboring areas (Reid, H. and Huq, S. 2005; and Tallis *et al. 2008*).). Loss of mangrove area has been estimate to increase in expected storm damages on the coast of Thailand by US $585,000 or US $187,898 per km2 (in 1996 $), based on damage data from 1979□96 and 1996□2004 respectively (Stolton et al, 2008). Recent studies in the Gulf of Mexico suggest that mangrove□related fish and crab species account for 32 percent of the small□scale fisheries landings in the region and that mangrove zones can be valued at $37,500 per hectare annually (Aburto□Oropeza et al., 2008). In Surat Thani, Thailand, the sum of all measured goods and services of intact mangroves exceeded that of shrimp farming from aquaculture by around 70 percent ($60,400) (Balmford et al., 2002).

Coral reefs are another ecosystem for which conservation and/or sustainable use produces ecological, social and cost-effective benefits. The coral reefs are evaluated by the IPCC (2007) as one of the most vulnerable systems to be impacted to different climatic and non-climatic stresses, including extreme events. The global net value of coral reefs relating to fisheries, coastal protection, tourism, and biodiversity, is estimated to total $29.8 billion per year (Ash, *et al.* 2007). The *Impacts of climate change on coral reefs* of the Cross-chapter case studies (Parry *el al, 2007)* suggest that the "coral reef crisis" is the result of complex and synergistic interactions among global- scale climatic stresses and local scale, human stresses like coastal development, marine pollution, over-exploitation and destructive fishing and sediment and nutrients from inland. A meta-analysis of data from 1977 to 2001 showed a reduction of the reef area on the Caribbean by 17 % in the year after a hurricane and the recovery period could be more than 8 years. Analysis of the coral bleaching in the region showed relationships with the variations in the El Nino Southern Oscillations and the atmospheric dust. The hurricanes undercut local shore protection. The coral degradation has negative impacts on local communities, through the loss of fishing livelihood, protein reduction, and loss of tourism incomes and the increment of the coastal erosion (Ash, *et al.* 2007). A synthesis of economic studies examining exploitation of Philippine reefs demonstrated that, despite high initial benefits, destructive fishing techniques provided fewer benefits than did sustainable fishing. Unsustainable fishing reduced social benefits and had a total economic value of $870/ha. By comparison, a healthy reef which provides tourism, coastal protection and fisheries had a total economic value of $3300/ha (Balmford et al., 2002, 2004). Recent study from Peduzzi, P. *et al*, (2010) quantified the sea grass and the coral reef role for tropical cyclone protection in Jamaica.

4. Coastal Zones Adaptation

The Convention of Biological Diversity (2009) consider the resilience of biodiversity to climate change can be enhanced by reducing non-climatic stresses in combination with conservation, restoration and sustainable management strategies of the ecosystems. This can be achieved through a reduced dependency on hard approach (e.g. intrusive coastal development, alternation, imposed land use practices) while empowering soft approach. To support the sustenance of soft approach, it is necessary to manage/prevent pollution discharge from upland/upstream; control of exploitation of resources and destructive fishing; and sustain fresh water flow through drainage basin. The restoration of the ecosystems and creation of coastal and marine protected areas with local knowledge and local participation are also integral to the overall adaptation approach. There needs to be sufficient political will to bridge between administrative or political boundaries to focus on the "whole coastal ecosystem" rather than species or specific locales. Careful land use planning, adaptive management, enhanced local resilience and participation in resource use and sustenance are fundamental to succeed in adaptation with soft approach.

A number of studies that support the role of the coastal ecosystem based adaptation note that it has limitations (e.g., Kerr and Baird, 2007). The coastal ecosystems will not reduce impacts in all the cases. In the face of dwindling resource base, growing demand/use for resources, and increased environmental extremes, "soft coastal defense" should be promoted with reduced "hard defense" structures (Campbell *et al*, 2009). The biodiversity based adaptation measures coupled with "mixed defenses" are receiving increased attention in the developing countries particularly Small Island Developing States (SIDS), where adaptive capacity is low and local communities depend upon their natural resources (Cherian, 2007). The situation is similar for the Least Developing Countries (LDCs).

5. Conclusions

The scientific literature on the role of the biological diversity to climate change adaptation is insufficient, but there is growing evidence suggesting that coastal ecosystem-based adaptation can be a cost-effective adaptation strategy (Campbell *et al*, 2009 and ProAct Network. 2008). The approach will enhance ecosystem resilience and thus enable continued goods and services provision to communities.

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Case Study 9.18. Linking Disaster Risk Reduction and Climate Change Adaptation – Cyclones in Bangladesh

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1. Introduction

Bangladesh experiences on average a severe tropical cyclone (wind speed 90-119 km/h) every three years (UNDP, 2004; World Bank 2010). Among the many tropical cyclones over the last 4 decades, Bhola in 1970, Gorky in 1991 and Sidr in 2007 proved to be the most severe in terms of their intensity and associated storm surge heights. All these were extreme events but the loss of life and morbidity have been considerably reduced with each succeeding event as shown in Table 9-2.

[INSERT TABLE 9-2 HERE:
Table 9-2: ___________.]

The 1970 Bhola cyclone is the deadliest tropical cyclone ever recorded in Bangladesh and one of the most catastrophic disaster events of the 20th century (Haque and Blair, 1992; GoB, 2008). Although two subsequent cyclones (Gorky in 1991 and Sidr in 2007) had comparable severity in terms of intensity and storm surge, and exposed far greater number of people than Bhola, the loss of life for those events was dramatically reduced compared to Bhola.

2. What Improvements were Made Over the Years?

The disaster management system, led by a full-fledged ministry after independence of Bangladesh (in 1971) has evolved over period with extensive institutional arrangements from national to local level. The key DRR measures that make the national system in Bangladesh increasingly effective against cyclone hazards and associated storm surges may be attributed to three concrete steps led by the Government in partnership with donors, NGOs, humanitarian organisations, and mostly importantly by involving the coastal vulnerable communities themselves.

First, the construction of cyclone shelters in the coastal regions has provided safe refuge to coastal populations. These shelters are multi-storied buildings with varying capacities 500 to 2500 people (Paul and Rahman, 2006) and are raised on platforms above ground-level to resist storm-surges. Also, killas (raised earthen platforms) which usually accommodate 300 – 400 livestock have been constructed in the cyclone-prone areas to safeguard livestock from storm surges (Haque, 1997).

Second, the coastal volunteer network, established under the cyclone preparedness programme (CPP), has proved time and again an effective mechanism for dissemination of cyclone warnings among the coastal communities and for time-critical actions on the ground for safe evacuation of vulnerable populations to cyclone shelters (Paul 2009). They are skilled and equipped volunteers having defined and time-critical responsibilities to help vulnerable coastal population at times of disaster emergency. These volunteers helped evacuation of around 350,000 people to cyclone shelters during Gorky in 1991 and, with an increased number of cyclone shelters and volunteers by sevenfold and twofold respectively, a total of 1.5 million people had been safely evacuated prior to landfall of Sidr in 2007.

Third, there has been a continued effort to improve forecasting and warning capacity in Bangladesh. A Storm Warning Center (SWC) has been established in the Meteorological Department and system capacity has been enhanced to alert to a wide range of user agencies including DMB (Disaster Management Bureau), CPP network, NGOs, the media, and local administration with early warnings and special bulletins soon after the formation of tropical depressions in the Bay of Bengal (Chowdhury, 2002). Periodic training and drilling practices are conducted at the local level for CPP volunteers for effective dissemination of cyclone warning and for raising awareness among the populations in the vulnerable communities. Table 9-3 lists the key improvements in the above three measures for reducing disaster risks from tropical cyclones in Bangladesh.

[INSERT TABLE 9-3 HERE:
Table 9-3: Key improvements for reducing disaster risks from tropical cyclones in Bangladesh.]

Added to these are many other hard and soft measures and local adaptive practices that have contributed to increased resilience of the coastal populations (Paul, 2009). The expansion of embankments and reforestation programs along the coasts and offshore islands has reduced the impact of Sidr significantly. Since 1959, more than 5,500 km of coastal embankments has been constructed in the coastal districts to support agriculture and protect crops and properties from saline tidal flooding (GoB, 2008). The Sundarbans, the world's largest mangrove forest, lies along the south-western coast of Bangladesh. Cyclones Bhola and Gorky had landfall in the middle and eastern coast with limited or no forest barriers. On the contrary, Sidr had landfall in western coast covered by the Sundarbans, which cushioned and reduced the impacts considerably (Paul, 2009).

Sustained and targeted assistance at the community level by Government, NGOs and humanitarian partners and social safety net programmes in the disaster vulnerable regions are reported to have significantly contributed to, and enhanced community resilience and capacity to cope with extreme events (Karim and Mimura, 2008). Coastal reforestation has been a priority intervention in the coastal region for reducing the thrust of storm surges and stabilising the coast (Karim and Mimura, 2008; World Bank, 2010).

3. Can Vulnerability be Further Reduced?

The existing number of cyclone shelters and killas in Bangladesh are reported to be far from adequate to accommodate the increasing size of the number of coastal population and assets (GoB, 2008; Islam, 2004). Sometimes these are located at a distance of more than 3.5 miles (5.6 km) apart. Studies have shown that it is difficult for the coastal populations to take refuge at times of emergency unless the cyclone shelter is located within the proximity of 1 mile (1.6 km) (Paul 2009). A total of 1,576 cyclone shelters (40% of total) were damaged by river erosion or abandoned for their dilapidated conditions due to lack of maintenance. Most of the casualties during Sidr took place in those offshore islands where cyclone shelters are either absent or inadequate in numbers or not in usable condition (GoB, 2008). As reported in an epidemiological assessment, all of those who sought refuge in concrete or building structures survived from Gorky in 1991(Bern et al., 1993). Multi-purpose use of cyclone shelters is now increasingly recognised as an effective way to promote local development as well as to ensure regular maintenance for their effective use during cyclone emergency (Chowdhury 2002).

Proper maintenance of the embankments and polders can further reduce the coastal vulnerability significantly. Lives were saved, and damages and property losses were much lower in places during Sidr where structures had been properly maintained and had not eroded (GoB, 2008).

In the aftermath of Sidr, a number of initiatives are in place in Bangladesh to reduce the future risks from extreme tropical cyclone events. Minimum specification for cyclone resistant houses is now standardized in the recovery efforts in housing sector. The recovery action plan of the Government, supported by its development partners and NGOs, includes DRR as an important element (GoB, 2008).

While the existing risk reduction measures in Bangladesh have achieved significant progress in cyclone preparedness and reduction of mortality, climate change may increase the risk to coastal communities because of the changes in the characteristics of extreme events and sea level rise (IPCC, 2007; Karim and Nimura 2008). Bangladesh is experiencing rising sea level along its coast due to global warming (Unnikrishnan, 2006). An increased number of severe cyclones (category 4 and 5 of Saffir-Simpson hurricane scale) has been observed over the North Indian Ocean in the recent history. Four major cyclones have formed since 2006 as compared to a total of eight major cyclones in the previous 25 years (Webster, 2008). These observed recent increases should be viewed in light of the known deficiencies in the data used to identify them (Ch. 3, section 3.2.1). Numerous data heterogeneities exist in the historical tropical cyclone record (e.g., Landsea et al. 2006). A known heterogeneity was introduced into the Northern Indian Ocean cyclone data as recently as 1998 when the launch of the Meteosat-7 satellite mitigated a longstanding problem with oblique satellite views of the Indian Ocean and associated biases in tropical cyclone intensity estimates (Kossin et al., 2007). Still, attempts at data homogenization have been made, and an increasing trend in the intensity of strongest Northern Indian Ocean cyclones since 1983 has been identified (Elsner et al., 2008). Confidence in projections of tropical cyclone changes at the regional level is low, however, particularly projections of frequency changes (Ch. 3, section 3.4.4.3; Knutson et al., 2010).

The Comprehensive Disaster Management Programme (CDMP) initiative of the Government of Bangladesh is designed to build risk reduction capacity and strengthen the disaster management system by adopting multi-hazard, multi-sector and multi-stakeholder approaches. Climate change is an integral part of the risk reduction model pursued by GoB under this programme.

CDMP is making efforts to institutionalise climate modelling and downscaling in Bangladesh for better understanding and national and sectoral planning for climate change adaptation. Several studies have also been commissioned to guide future actions for adaptation to climate change, for example on the likely environmental costs of climate change, and economic modelling of the likely infrastructure needs in Bangladesh. To support local level adaptation, CDMP has developed tools like community risk assessment (CRA) and local action plans and these are now increasingly used by government and NGOs for systematic and participatory assessment of disaster and climate risks and vulnerabilities.

4. Lessons and Key Messages

The impacts of climate change in Bangladesh can mostly be considered as a magnification of natural and historical risks. Most impacts are not new, but are potentially increased in severity. Bangladesh, at all levels from households through communities to the national government, has always been ‘adapting’ to these risks and threats (GoB, 2005).

The adaptation process must be localized so that communities can reorganize to address changing pattern of risks caused by climate change. Local level adaptation needs to be framed around adaptive local resources, adaptive capacity, and the empowerment of local social organization for decision-making, with adequate external resources and unhindered by outside constraints (UNU-EHS, 2009).

As with climate change adaptation, the non-negligible potential for an increase in future cyclone intensity combined with projections for sea level rise adds the need for a longer term perspective to DRR (IDS, 2008). Increased flooding associated with sea level rise threatens millions in coastal villages and communities in the region, so that the best and only viable DRR strategy is relocation, or adaptation to such changing conditions (Ahmed et al, 1999; GoB, 2005). Myers (2002) argues that climate refugees from Bangladesh alone might outnumber all current refugees worldwide.

The complexities and critical issues important for climate change adaptation (i.e. how to manage and cope with increased variability of extreme events) share much in common with disaster risk reduction measures. The changes in magnitude, intensity, frequency and spatial distribution of climate-driven extreme events is evolving and accelerating over the long term. The bringing together on DRR and CCA in Bangladesh is a good demonstration of how to make those engaged in CCA more aware and sensitive to extreme events, and also to bring the need for longer term strategies to the attention of those engaged in DRR.

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Case Study 9.19. Early Warning Systems

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1. Early Warning Systems for Disaster Risk Reduction and Climate Change Adaptation

Since the early 1990s, the annual number of humanitarian disasters worldwide has more than doubled largely as a result of increases in the frequency of hydrometeorological disasters (most notably flooding events). Regardless of the extent to which this increase is attributable to changes in the frequency and intensity of natural hazards as opposed to increases in vulnerability or exposure to these hazards (e.g., the numbers of people living in areas subject to such hazards), the effect has been a substantial increase in the threat posed by weather and climate extremes on human populations around the world. Despite these increases, improvements in early warning systems have contributed to decreases in the numbers of deaths, injuries, and loss of livelihood over the last thirty years (IFRC, 2009).

An early warning system is defined[17] as "the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss." This definition encompasses a wide range of factors are that may or, if effective, will contribute to effective responses to warnings, and emphasizes the point that an early warning system involves considerably more than just a forecast of an impending hazard. This need for more than just accurate predictions was stated in the the Hyogo Framework for Action (HFA) 2005-2015[18] which stressed that early warning systems should be *"people centered"* and that warnings need to be*" timely and understandable to those at risk"* and need to "*take into account the demographic, gender, cultural and livelihood characteristics of the target audiences*." Warnings also need to include *"guidance on how to act upon warnings."*

[INSERT FOOTNOTE 17 HERE: UNISDR Terminology on Disaster Risk Reduction, 2009: Available at http://www.unisdr.org]

[INSERT FOOTNOTE 18 HERE: Hyogo Framework for Action 2005-2015: ISDR, International Strategy for Disaster Reduction. www.unisdr.org]

In 2006, the United Nations International Strategy for Disaster Reduction completed a global survey of early warning systems. The executive summary opened with the statement that: *"If an effective tsunami early warning system had been in place in the Indian Ocean region on 26 December 2004, thousands of lives would have been saved. The same stark lesson can be drawn from other disasters that have killed tens of thousands of people in the past few years. Effective early warning systems not only save lives but also help protect livelihoods and national development gains. Over the last thirty years, deaths from disasters have been declining*[19]*, in part thanks to the role of early warning systems and associated preparedness and response systems"*[20]

[INSERT FOOTNOTE 19 HERE: Centre for Research on the Epidemiology of Disasters (CRED), "Thirty Years of Natural Disasters 1974-2003: The Numbers", Presses Universitaires de Louvain, 2004.]

[INSERT FOOTNOTE 20 HERE: Global Survey of Early Warning Systems. Prepared by UN International Strategy for Disaster Reduction for the United Nations, 2006. 46 pp. Available from United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR), International Environment House II, 7-9 Chemin de Balexert, CH 1219 Chatelaine, Geneva 10, Switzerland http://www.unisdr.org]

The focus of early warning systems should be to warn and inform the citizens and governments of changes on a seamless timescale stretching from minutes for immediate threats requiring urgent evasive action; to weeks for more advanced preparedness; to seasons and decades for climate variations and changes, and to provide a basis for disaster risk reduction and sustainable development. To-date most of the early-warning systems have been based on weather predictions, which provide short-term warnings often with sufficient lead-time and accuracy to take evasive action. However, the range of actions that can be taken if early warning systems are informed by no other climate information than short-range predictions is limited. Weather predictions often provide less than 24 hours notice of an impending extreme weather event, and options in resource-poor areas may not extend beyond the emergency evacuations of people. Thus although lives may be saved, livelihoods may still be destroyed, especially those of the poorest communities.

Partly because of the rapid growth in the number of humanitarian disasters, the disaster risk management community has become attentive to the risk of possible changes in weather and climate hazards as a result of climate change, in particular regarding changes in floods, droughts, heat waves and storms. Effective tools for weather and seasonal prediction (and early warning) are among the possible approaches to assist in adaptation to possible increases in the occurrence of weather- and climate-related hazards. However, with increasing uncertainty in the predictions at longer timescales, it is imperative that appropriate response strategies be identified to ensure that confidence is retained in the early warning system when anticipated hazards do not manifest. At the longer timescales, the appropriate responses may involve little more than no-regrets actions with forecasts providing one additional factor in the choice between competing priorities given finite resources (Braman et al. 2010; Tall et al. 2010); at the shorter timescales, as confidence in the prediction of specific anticipated hazards increases, more committed actions can be taken with the understanding that there remains some possibility of the hazardous event not occurring.

2. Examples of Benefits of Early Warning Systems

Predictions of hazardous events can contribute to disaster risk reduction and sustainable development (McBean, 2007; 2010). There are examples in the past of major benefits of early warning systems (Einstein and Sousa 2007). In 1977, a major cyclone resulted in about 20,000 deaths on the east coast of India. In the years that followed, an early warning system was established, complete with meteorological radars and emergency plans, and many lives were saved as a result when the same area was hit again by cyclones of similar strength in 1996, when about 100 deaths occurred, and in 2005, when the death toll was just 27 (UNISDR, 2009). Predictions of land-fall for tropical cyclones are very important (Davis et al., 2008). As presented in Case Study 1 Tropical Cyclones, major reductions in loss of life were achieved "*after the devastating cyclone of 1970, the Bangladesh government initiated several structural and non-structural measures to reduce the cyclone risk (Paul, 2009)*". These measures included implementation of an early warning system. However, accurate predictions alone are insufficient for a successful early warning system as is demonstrated by the case in the United Kingdom, a country which regularly experiences flooding. Severe damage and health problems followed flooding in 2007 due to warning communication that was insufficiently clear, issued too late, and inadequately coordinated, so that people, local government and support services were unprepared (UNISDR, 2009).

While most of the successfully implemented early warning systems to date have focused on shorter timescales [for example, for tornadoes (Doswell et al. 1993)], benefits of improved predictions on the sub- to seasonal scales have been reviewed (Nichols 2001; Brunet et al 2010). Since hazardous atmospheric events occur on timescales from minutes for tornadoes, for example, through seasons and decades in terms of the climatically-changing occurrences of extremes (McBean, 2000), and since planning for hazardous events involves decisions across a full range of timescales, *"An Earth-system Prediction Initiative for the 21st Century"* covering all scales has been proposed (Shapiro et al. 2007; 2010). With improvements in numerical weather models (Simmons and Hollingsworth, 2002) and stochastic design (Medina-Cetina and Nadim, 2008), early warning systems based on medium-range and seasonal forecasts for flood hazards across Europe and West Africa have been considered (Bartholmes et al. 2008; Tall et al. 2010).

Similarly, there have been important developments in recent years in the area of subseasonal and seasonal-to-interannual prediction, leading to dramatic improvements in predictions of weather and climate extremes (Nicholls, 2001). Some of these improvements, such as the use of soil moisture initialization for weather and (sub-) seasonal prediction (Koster et al., 2010), have potential for applications in transitional zones between wet and dry climates, and in particular in mid-latitudes (Koster et al., 2004). Such applications may be potentially relevant for projections of temperature extremes and droughts (Schubert et al., 2008b; Koster et al., 2010). On decadal and longer timescales, predictions are improving and could form the basis for early-warning systems in the future (Meehl et al., 2007, 2009; Palmer et al, 2008; Shukla et al., 2009, 2010).

Methods for improving predictions remain a very active area of research, and significant further progress may be reached in coming years. However, for such predictions to be of use to end users, improved communication will be required to develop appropriate indices relevant for specific regional impacts. For example predictions of the probability of climate variables such as average temperatures in the format of terciles commonly used in seasonal-to-interannual climate predictions may not be the most relevant information for impacts. A better awareness of such issues in the climate modelling community, from improved interactions with the disaster risk management community (and other user communities), may lead to the development of more useful applications for weather and climate hazard predictions. Such prediction systems, if carefully targeted and of sufficient accuracy, can be a useful tool for reducing the risks related to climate and weather extremes.

3. <u>What can We Learn from Experience with Subseasonal and Seasonal-to-Interannual Climate Predictions?</u>

Developing resiliency to weather and climate involves developing resiliency to its variability on a continuum of timescales, and in an ideal world early warnings would be available across this continuum. However, investments in developing such resiliency are likely to be primarily informed by information only over the expected lifetime of the investment, especially amongst poorer communities. For example, in deciding what crops to grow next season, while some consideration may be given to longer-term strategies, the more pressing concern is likely to be the expected climate conditions over the next season. Indeed, there is little point in preparing to survive the impacts of possible disasters a century hence, if one is not equipped to survive more immediate threats. Thus, within the disaster risk management community, preparedness for climate change necessarily involves preparedness for climate variability.

Despite this inevitable focus on shorter-term survival and hence interest in warnings of hazards in the near-term, even in this context the longer timescales cannot be ignored if reliable predictions of climate variability are to be made. For example, considerations of changing greenhouse gas concentrations are important even for seasonal forecasting, because including realistic greenhouse gas concentrations can significantly improve forecast skill (Doblas-Reyes et al., 2006; Liniger et al., 2007). Similarly, adaptation tools traditionally based on long-term records (e.g., streamflow measurements over 50-100 years) under the assumption of stationary climate conditions, may create a bias towards obsolete adaptation (e.g., Milly et al., 2008). Thus reliable prediction and successful adaptation are both impossible as long as a myopic perspective on a single timescale, be that climate change, seasonal, or weather scale, is retained.

While there appear to be obvious potential benefits of early warning systems that span a continuum of timescales, for much of the disaster risk management community the idea of preparedness based on predictions is a new concept: the community has largely operated in a reactive mode, either to disasters that have already occurred, or in emergency preparedness for one that is anticipated to occur with high confidence in the immediate future. The possibility of using weather and climate predictions longer than a few days to provide advanced warning of extreme conditions has been only a very recent development. Despite what has been over a decade of operational seasonal predictions in many parts of the globe, examples of the use of such information by the disaster risk management community are limited, for a number of reasons. Not least of these reasons are the large uncertainties in the predictions, and difficulties in understanding their implications. Most seasonal rainfall predictions, for example, are presented in a so-called probabilistic tercile format: probabilities are provided that the total rainfall over the coming few (typically three) months, and averaged over large areas (typically tens of thousands of square kilometres), will be amongst the highest and lowest third of rainfall totals as measured over a historical period. Not only are the probabilities almost invariably lacking in sharpness (highest probabilities are most frequently around 40% or 45%, compared to the climatologically expected probability of 33%), but the target variable of the seasonal rainfall total does not necessarily map well onto flood occurrence. Although higher-than-normal seasonal rainfall will often be associated with a higher risk of floods, it is possible for the seasonal rainfall total to be unusually high but yet for no flooding to occur because of the frequent occurrence of moderately heavy rain. Alternatively, the total may be unusually low, but yet flooding might occur because of the occurrence of an isolated heavy rainfall event (see also chapter 3 for a discussion of these aspects). Thus even when seasonal predictions are understood properly, it may not be obvious how to use them – the uncertainty in the predictions is very high and the predicted variable may not be of immediate relevance. These problems emphasize the need for the development of tools that can translate such information to quantities directly relevant to end users, and thus for better communication between modelling centres and end users. Where targeted applications have been developed, some success has been reported (e.g., for malaria prediction, Thomson et al., 2006; Jones et al., 2007). Nonetheless, there can be additional obstacles such as policy constraints, which may restrict the range of possible actions that could be taken. Technical constraints, such as limited telecommunications infrastructure, can also limit the utility of predictions.

Notwithstanding these obstacles to the use of seasonal predictions in disaster risk management, the successful use of such predictions has been possible, and can be promoted by attending to the obstacles. For example, the large uncertainty in the information, and, to some extent, some of the policy constraints, may be surmountable by identifying no-regrets strategies. While all preparative actions have some direct cost, and so it is impracticable to be always prepared for all possible eventualities, seasonal predictions can help to prioritize amongst a list of actions. A clear instance of taking such action is provided by the International Federation of Red Cross and Red Crescent Societies (IFRC) West and Central Africa Zone (WCAZ) flood preparedness and response during 2008. In response to a set of predictions for the rainfall season for the region issued in May 2008, actions were taken to pre-position relief items, to improve disaster response capacity through trainings, to develop flood contingency plans, and to launch pre-emergency funding requests for preparedness activities and response. Although it is impossible to quantify the benefits of these actions, evidence suggests that lives were saved and the costs of relief reduced (Braman et al., 2010).

4. Relationship to Key Messages

Early warning systems directly contribute to climate change adaptation and disaster risk reduction and relate to several of the key messages of this Special Report. Early warning systems can increase effectiveness of adaptation strategies and practices by providing information on the type of extreme events that may occur in the near and longer-term futures. This sense of “seeing the future”, including projected risks, anticipatory strategies and actions, is essential towards key messages: (2) effectively preparing for, responding to, and recovering from extreme events and disasters require understanding current and projected risks; (16) Effective disaster risk management in a changing climate is facilitated by anticipatory strategies within and between sectors, with strong co-ordination; and (20) realizing adaptation potentials requires anticipation of vulnerabilities and anticipatory actions.

Key message (9) “risk can never be reduced to zero, but it can be reduced and managed” refers to the problems with assuming a stationary climate. Effective early warning systems on longer timescales will convince disaster risk managers that this is inappropriate. By incorporating longer-term early warning systems into disaster risk management, (key message 11) “improving current risk management can facilitate adaptation to climate change”, noting that managing [rising] uncertainty requires anticipatory action. Early warning systems can also contribute to “climate smart disaster risk management (key message 14).

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9.4. Synthesis of Lessons Learned from Case Studies

This chapter examined case studies of extreme climate events, vulnerable regions and methodological-management approaches in order to glean lessons and good practices. This is an important role because it adds context and value to the information. Warming trends can be predicted and the occurrence of extreme events explained, even identifying the regions that are most at risk. The role of case studies is to contribute a more focused analysis which conveys the reality of the event: the extent of human loss and financial damage; the response strategies and their successes and failures; prevention measures and their effect on the overall event; and even cultural or region-specific factors that may influence the outcome. Most importantly, case studies provide a medium through which to learn practical lessons about success in disaster risk reduction and climate change adaptation. These will prove useful as states and people try to adapt to a continually changing climate.

The case studies in this chapter illustrate and demonstrate issues that need to be improved and they illustrate all three groups of concerns. Throughout the studies several recurring themes and lessons occurred. Since they hold importance in so many different scenarios and against so many different types of threats, it is clear that they should be highlighted for use by policymakers. The first such lesson is to invest in knowledge. In the case studies that dealt with sea-level rise, typhoons, floods and droughts, as examples of extreme events, a common factor was the need for greater amounts of information on threats before the events occur. In certain scenarios, this could mean investing in an early warning system. In others it was a demand for investment into greater and more accurate weather services in order to allow better planning for farms and other agricultural workers. Across the case studies the need for clearer understanding of health impacts and the benefits of safer hospitals and health care facilities is identified. In all cases, the point was made that with greater information available it would be possible to know the risks better and ensure that any response strategies were adequate to face the coming threat. Research is required to improve our knowledge and it needs to include an integration of natural, social, health and engineering science and their application.

The second major lesson was that due to the amount of damage that one extreme event can cause, and further, due to the all-encompassing nature of that damage, an integrated approach is needed in order to properly address these threats. Though present to some extent throughout all case studies, this lesson was particularly evident in the case studies that dealt with intersectoral issues, health, compound events and repetition of events. Here, the point resounded that if an extreme event could be felt in all aspects of life, clearly it was essential to study its impacts in all areas. This would contribute to a better understanding of the impacts of extreme events, which would hopefully allow for better and better-rounded risk reduction strategies. The approaches need to be integrated and multilevel as well as examing both the direct and indirect impacts. With respect to these impacts, they need also to be studied from the persepctive and with those who receive the impact (the victims). There is as yet limited material (scientific and systematic) on how the victims see and understand impacts.

The third lesson of note was the promotion of international cooperation in disaster risk reduction or climate change adaptation strategies. Disaster risk reduction (DRR) and climate change adaptation (CCA) are mutually reinforcing and similar directions in measures are needed. Where there is uncertainty as to the details of climate change in the future, this uncertainty can be reduced, in a sense, through the risk reduction approaches of DRR, noting that the low probability event but with very great consequences needs to be part of the planning and response approach. This was a particularly important message since this type of collaboration can be beneficial in many different ways. Findings in the case studies are clearly transferable into practice for many regions and countries and the positive nature of DRR and CCA, bringing a better coherence is important. Trans-boundary cooperation must happen at global and local level as in the end local adaptation or DRR actions across boundaries will make a difference. There is considerable experience on how to launch trans-boundary collaboration for trade or military action. But how such collaborations can be designed and launched and governed such that they promote integration of DRR and CCA is more difficult and it is suggesed that pilot projects are needed which could be then studied and replciated as appropriate.

Transboundary issues relating to resources such as rivers or lakes, demand cooperation in order to come to mutually agreeable terms on usage and access. Further, because the world is so interconnected, it is important that issues or vulnerabilities within a local area are addressed since they affect not only the state they belong to but the entire region or, in some cases, the international community at large. For instance, a drought in Indonesia, the Philippines or Vietnam, could seriously impact the availability of rice in China or Japan since they must import rice to feed their populations. This is especially relevant given the food shortages of the last few years. The case study regarding risk transfer provided a good example of how closely bound countries can work together to relieve their collective vulnerability. Finally, international cooperation is demanded because of the unequal nature in which the impacts of climate-related extreme events will be felt. As stated in various sections throughout the chapter, the most vulnerable areas are poor, coastal nations. Given that they are unable in many cases, to institute adaptation or risk reduction measures, it is essential to their survival that the international community contributes to their efforts. In others, it will call for guidance when setting up risk management measures, and in the most extreme cases, it may call for some countries to accept refugees from states who suffer from disasters. Holistic all hazards approaches are vital in DRR and CC and this includes the recognition of previous generational errors in siting cities in vulnerable areas and how or if these decisions can be revisited.

The last lesson for policymakers is that in order to implement a successful DRR or CCA strategy, legal and regulatory frameworks are needed to ensure direction, coordination and effective use of funds. The case studies are helpful in this endeavour as passed legislaturion has created a framework for governance of disaster risks. While this type of suggestion is mainly for national governments, it holds an important message for international governance and institutions as well. Here, cooperating with other countries to attain better analysis of the threat, it is possible to establish frameworks that will allow institutions to change their focus with the changing threat, therefore retaining their usefulness. This cooperation needs to be at the local through national to international levels. Here and in other ways, civil society has an important role.

Repeatedly throughout the chapter, reference was made to ‘smart investment’ with regard to risk management measures. The idea overall was that it is better to invest in preventative and adaptation based tools than in the response to extreme events. This includes the need to invest in primary to higher education and research and monitoring. The reasoning behind such statements was that if the disaster has already occurred, the damage has been done. The main goal of both disaster risk reduction and climate change adaptation is to reduce the risk and vulnerability of people and property. In other words, measure should be taken to reduce the damage that is inflicted as a result of extreme events. Investment in increased knowledge and warning systems, adaptation techniques and tools and preventative measures will cost money now, but save money and lives in the future.

Table 9-1: Examples of mechanisms for managing risks at different scales

	Local *Households, SMEs, farms*	***National*** *Governments*	***International*** *Development organizations, donors, NGOs, …*
Non-insurance mechanisms			
Solidarity	Help from neighbors and local organizations	Government post/disaster assistance; government guarantees/bail outs	Bi-lateral and multi-lateral assistance, regional solidarity funds
Informal risk sharing	Kinship and other mutual arrangements	Government diversions from other budgeted programs	Remittances
Savings and credit (inter-temporal risk spreading)	Savings; micro-savings; fungible assets; food storage; money lenders; micro-credit	National reserve funds; domestic bonds	Regional pools, post-disaster credit; contingent credit; emergency liquidity funds
Insurance mechanisms			
Insurance instruments (risk transfer and pooling)	Property insurance; micro-insurance; crop and livestock insurance; weather hedges	National insurance programs; sovereign risk transfer	Re-insurance; regional catastrophe insurance pools
Alternative risk transfer			Catastrophe bonds; risk swaps, options, and loss warranties

Source: Linnerooth-Bayer and Mechler, 2009

Table 9-2:

Cyclone events	Storm Surge	Maximum Wind Speed	Number of Affected Districts	Number of Affected People	Mortality
Bhola (1970)	6-9 m	223 km/h	5	1,100,000	300,000 – 500,000
Gorky (1991)	6-7.5 m	225 km/h	19	14,000,000	138,000
Sidr (2007)	Up to 10 m	Up to 240 km/h	30	6,900,000	3,400

Sources: Paul, 2009; GoB, 2008; Karim amd Mimura,2008; CRED, 2009

Table 9-3: Key improvements for reducing disaster risks from tropical cyclones in Bangladesh.

Cyclone event	Cyclone shelters (No)	CPP Volunteers	Cyclone Warning System	Population evacuated
Bhola (1970)	Nil	Nil	No warning capacity*	Nil
Gorky (1991)	512	20,000	Limited capacity	350,000
Sidr (2007)	3976	43000	Storm Warning Centre equipped with modern technology and access to mobile phones in coastal regions	1,500,000

(*Forecast was issued by Indian Meteorological authority and communicated to Cox's bazaar in the evening before land fall of Bhola Cyclone. Reliable information is not available)

Sources: GoB, 2008;ISDR, 2009; Sommer and Mosley, 1972; Paul 2009.

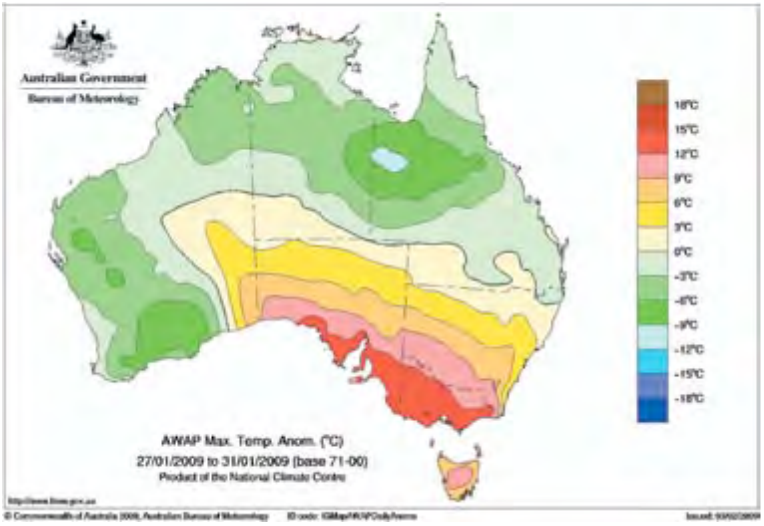


Figure 9-1: Maximum temperature anomalies for the period 27–31 January 2009.

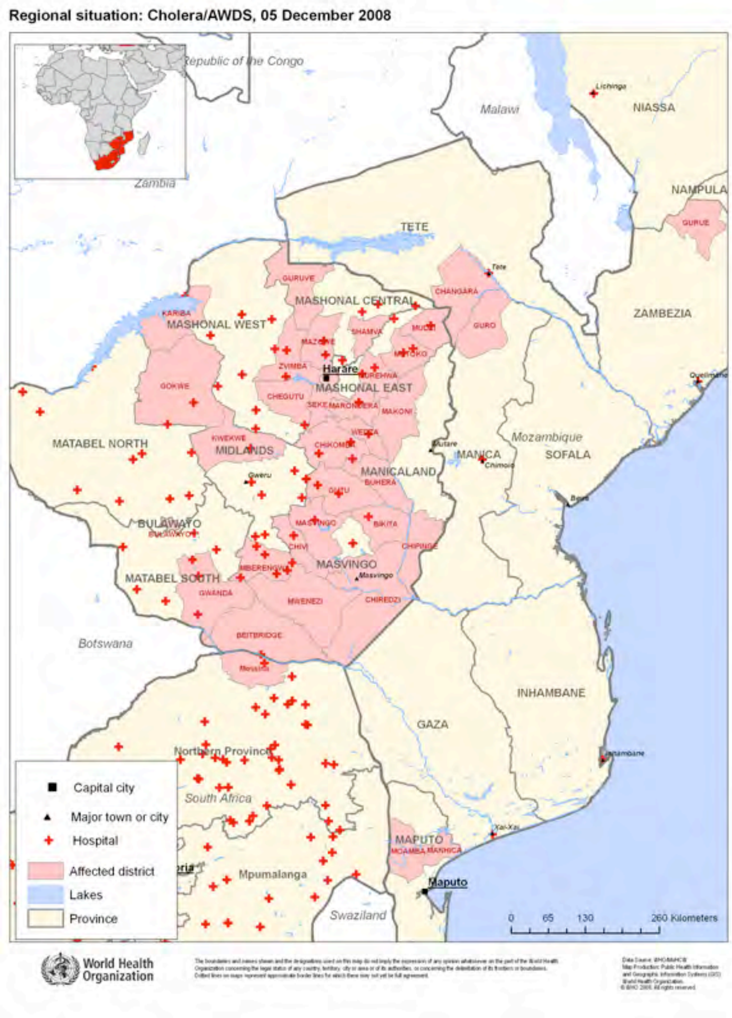
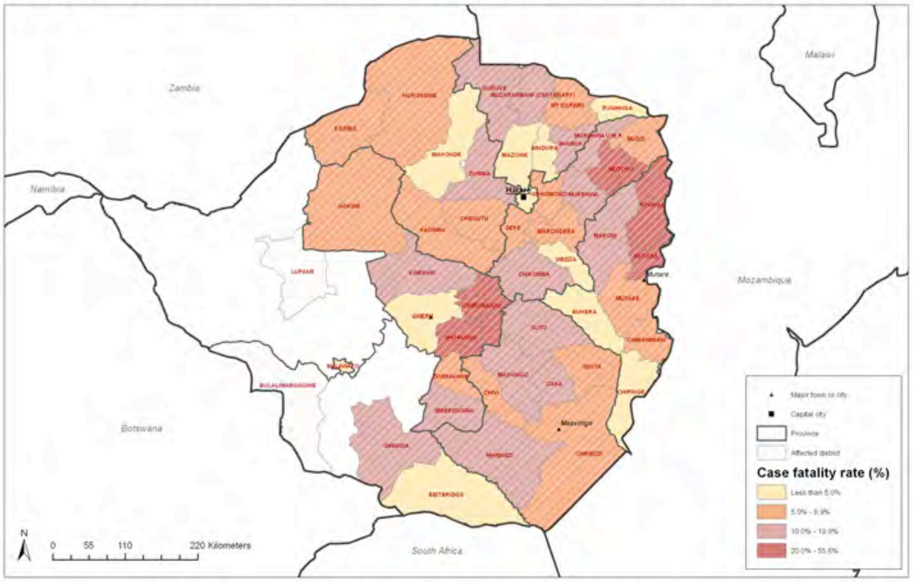


Figure 9-2: Regional spread of the 2008 Zimbabwe epidemic.

Cholera situation in Zimbabwe: Cumulative Case Fatality Rates by district, from August 2008 - 11 January 2009



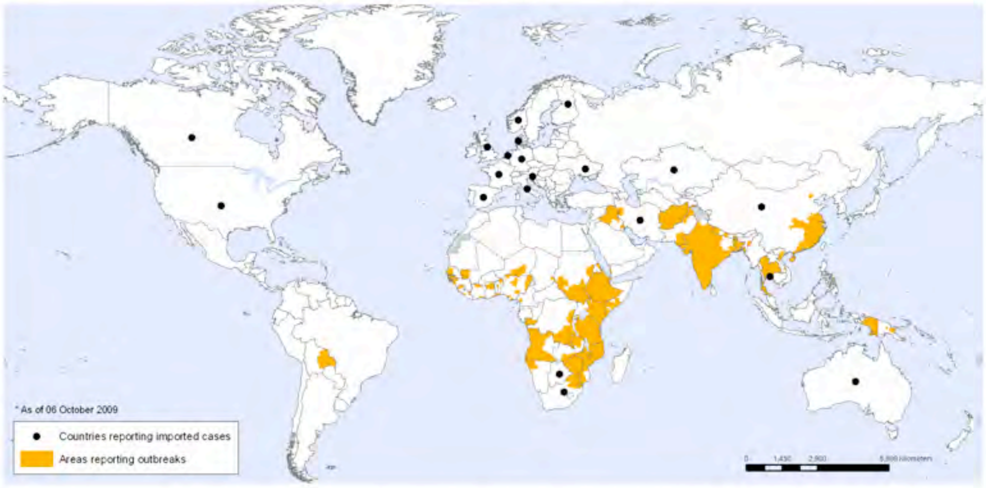
World Health Organization

The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement. © WHO 2008. All rights reserved

Data Source: WHO
Map Production: Public Health Information and Geographic Information Systems (GIS)
World Health Organization.

Figure 9-3: Case fatality rates for Zimbabwe by district.

Cholera, areas reporting outbreaks, 2007–2009*



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Data Source: World Health Organization
Map Production: Public Health Information and Geographic Information Systems (GIS)
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Figure 9-4: Cholera outbreaks, 2007-2009.