IPCC SREX Summary for Policymakers

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A. CLIMATE, EXTREMES, AND DISASTERS: CONTEXT AND HISTORY

Weather and climate events impact human society and natural ecosystems. The character and severity of impacts, as well as the risk of disasters, result from the exposure and vulnerability of human systems and the sensitivity of natural systems, and from the type, magnitude, and extent of weather and climate events. This report assesses the influences of climate change on exposure and vulnerability and on weather and climate events, with a focus on extreme events, extreme impacts, and disaster risk. It also examines the potential for adaptation and disaster risk management to reduce risks and impacts and the wider implications for sustainable development.

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Box SPM.1: Extreme Events, Exposure, and Vulnerability

Extreme events are defined in this report as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) end of the range of observed values of the variable.[1] What is called an extreme event will vary from place to place in an absolute sense (e.g., a hot day in the tropics will be a different temperature than a hot day in mid-latitudes) and possibly in time, given some adaptation. Extremes in some climate variables (e.g., drought) may not necessarily be induced by extremes in meteorological variables (precipitation, temperature) but may be the result of an accumulation of moderate weather or climate events.

[INSERT FOOTNOTE 1: Definitions of thresholds vary, but values with less than a 5% or 1% or even lower chance of occurrence during a specified reference period (generally 1961-1990) are often used. Absolute thresholds (rather than these relative thresholds defined probabilistically relative to the range of possible values of a variable) can also be used to identify extreme events (e.g., specific critical temperatures for health impacts).]

Exposure is defined in this report as the presence of people, livelihoods, environmental services and resources, infrastructure, and economic, social, and cultural assets in areas or places that are subject to the occurrence of physical events and that thereby are subject to potential future loss and damage.

Vulnerability is defined in this report as the susceptibility or predisposition for loss and damage to human beings and their livelihoods, as well as their physical, social, and economic support systems when affected by hazardous physical events. Vulnerability includes the characteristics of a person or group and its situation that influences its capacity to anticipate, cope with, resist, respond to, and recover from the impact of a physical event.

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A changing climate can affect the frequency, intensity, or duration of extreme events and may result in unprecedented, previously unobserved extremes. Many extreme events are the result of natural climate variability (including phenomena such as El Niño Southern Oscillation – ENSO), and natural decadal or multi-decadal variations in the climate provide the backdrop for anthropogenic changes. Irrespective of the magnitude of any anthropogenic changes in climate over the next century, the occurrence of a wide variety of natural weather and climate extremes can be expected. [3.1]

Extreme impacts and disaster risk are strongly dependent on patterns and trends in extreme weather and climate events, exposure, and vulnerability. Extreme impacts can arise when extreme events intersect with people and their natural, social, and economic support systems; the severity of impacts depends on the vulnerability and exposure of the affected people and systems. Extreme impacts result in climate-related disasters when they produce widespread human, material, economic, or environmental damage and cause severe alterations in the normal functioning of communities or societies. Given variations in exposure and vulnerability, disasters and extreme impacts can arise from weather or climate events that are not extreme in a statistical sense. This can occur when a critical threshold in a social, ecological or physical system is crossed, or when two or more non-extreme events occur simultaneously or sequentially. Additionally, some extreme events may not lead to disasters and extreme impacts when exposure or vulnerability is low. In some cases, extreme events can have positive impacts on some ecosystems and economic sectors. [1.2; 2.1; 2.2; 2.5; 2.7; 3.1; 4.1; 4.3]

Disasters cause significant socioeconomic impacts in all countries, but low- and middle-income countries experience higher fatalities and direct economic losses relative to annual GDP (*high confidence*). Disasters create barriers for continued socioeconomic development (*medium confidence*). Disasters can cause important adverse macroeconomic and developmental effects, such as increased poverty, reduced direct and indirect tax revenue, dampened investment, and reduced long-term economic growth. [4.6.3.1; 6.1]

Because most estimates of disaster losses are based on direct losses, often recorded only as monetized direct damages to infrastructure, productive capital stock, and buildings, they substantially underestimate the extent of losses. These estimates exclude indirect losses, including primarily the economic flows constituting livelihoods and economies and intangible losses including ecosystem services, human lives, quality of life, and cultural impacts. [4.6.1.1; 6.1]

There is *high confidence* that climate change will affect disaster risk not only through changes in the frequency, intensity, and duration of extreme events, but also through indirect effects on exposure and vulnerability. These indirect effects include impacts on the number of people who are in poverty or who suffer from food and water insecurity, on changing disease patterns and general health levels, and on settlement patterns. In some cases, indirect effects of climate change may reduce vulnerability and/or exposure, but in many cases, they will increase exposure and/or vulnerability, especially for groups and areas already among the most vulnerable. [2.7]

B. OBSERVATIONS OF VULNERABILITY, EXPOSURE, EXTREME EVENTS, IMPACTS, AND DISASTER LOSSES

Exposure and vulnerability are highly context specific and dynamic, varying widely across different locales and populations and shifting in response to physical, environmental, economic, social, cultural, institutional, and governance changes. Exposure of people and economic assets to extreme weather and climate events is increasing, but trends in vulnerability are increasing for some areas and groups and decreasing for others. People are differently exposed and vulnerable according to characteristics such as wealth, gender, age, race/ethnicity/religion, disability and health status, and class/caste. Lack of resilience and the capacity to anticipate, cope with, and adapt to change are important causal factors of vulnerability. [2.2; 2.4; 2.5; 2.7; 4.3.2]

There is evidence of changes in extreme events occurring over recent decades.
Since 1950, it is *very likely* that there has been an overall decrease in the number of unusually cold days and nights and an overall increase in the number of unusually warm days and nights on a global scale for land areas for which data are available. It is *likely* that this statement also applies at the continental scale in North America and Europe and *very likely* that it applies in Australia. There is *medium confidence* of a warming trend in temperature extremes in Asia. There is *low confidence* in observed trends in temperature extremes in Africa and South America. It is *likely* that the number of warm spells, including heatwaves, increased since the middle of the 20th century in many (but not all) regions. [3.3.1; Table 3.2]

It is *likely* that there have been statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than there have been statistically significant decreases, but there are strong regional and subregional variations in the trends. [3.3.2]

There is *low confidence* that any reported long-term increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities. [3.4.4]

There is *medium confidence* that, since the 1950s, some regions have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but also opposite trends exist. [3.5.1]

There is no clear and widespread evidence of observed changes in the magnitude/frequency of floods at the global level based on instrumental records, and there is thus *low confidence* regarding the magnitude and even the sign of these trends. [3.5.2]

There is evidence of widespread impacts of extreme events on biodiversity and ecosystems, based on observations of physiology, development, phenology, and carbon balance. Ecosystem services can be impaired by extreme events. Even though some ecosystems are adapted to or depend on particular extremes, ecosystem susceptibility to negative impacts of extremes is generally increased when ecosystems are already stressed by fragmentation, deforestation, urbanization, road and infrastructure corridors, environmental contamination, and residual damage from earlier events. [4.2.3.3; 4.3.5; 4.4.3]

Extreme events have impacts on sectors sensitive to climate conditions, such as water, food systems and food security, tourism, and public health. Settlements combine and concentrate the exposure of many sectors and their infrastructure, including energy, water, and transport, as well as most components of manufacturing and trade. Because of the connected nature of sectors, vulnerabilities in one sector can negatively impact others. [4.4]

There is *high confidence* that absolute losses from weather- and climate-related disasters are increasing. For weather- and climate-related disasters, recorded global annual accumulated losses have ranged (in USD 2009 values) from a few billion to as much as 250 billion (for 2005, the year of Hurricane Katrina). Over the period of 2000-2008, the Americas suffered the most direct economic damage in absolute terms from weather- and climate-related disasters, accounting for 55% of the total losses, followed by Asia (28%) and Europe (16%), while Africa accounted for only 0.6%. When expressed as a proportion of gross domestic product (GDP), estimated losses of natural disasters in developing regions are generally higher than those in developed regions. Disasters can cause even larger losses in small economies such as small island states. For example, average direct losses due to disasters to infrastructure, public buildings, and productive capital stock in Samoa have been reported to amount to 6.7% when measured against gross domestic product and averaged over all (disaster and non-disaster) years. [4.2.4; 4.6.3.1; Table 4-16; 6.1]

There is *high agreement*, but *medium evidence* that increasing losses cannot yet be formally attributed to anthropogenic climate change. There is *high confidence* that changes in exposure of people and economic assets, and in some cases changes in vulnerability, have been the major drivers of observed increases in disaster losses. The ability to attribute changes in disaster losses to anthropogenic climate change is limited by data availability; type of weather and climate events studied (e.g., many studies providing evidence of increasing losses focus on cyclones, for which there is *low confidence* in anthropogenic changes [3.4.4; Table 3.1]); confounding factors; and the methods used to normalize loss data over time. [2.7.1; 4.2.4]

C. PROJECTIONS OF VULNERABILITY, EXPOSURE, EXTREME EVENTS, IMPACTS, AND DISASTER LOSSES

Climate change, in addition to natural climate variability, can affect vulnerability, exposure, and the type and magnitude of extreme weather and climate events, thereby altering the potential for extreme impacts and the risk from disasters. Unprecedented, previously unobserved extreme events and impacts may result, and the possible occurrence of low-probability high-impact events, associated with the crossing of poorly understood thresholds, cannot be excluded. Non-linear feedbacks play an important role in either damping or enhancing extremes in several climate variables and related impacts. [3.1.4; 3.1.7; 4.2.1]

There is *high confidence* that trends in vulnerability and particularly in exposure will continue to be drivers of changes in risk patterns over the coming decades. Key factors determining these trends include population growth, changing demographics and health status, changing settlement patterns including urbanization, economic growth, environmental degradation, evolving science and technology, institutional and governance issues, and gradual shifts in climate and its variability. Important complexities arise from feedbacks among these drivers, accumulation and social amplification of risk, dynamic changes in vulnerabilities, and interactions among crises and disasters. [2.7; 2.9; 4.3.4; 4.4]

Confidence in projecting changes in the direction and magnitude of extreme events depends on many factors, including the type of extreme, as well as the region and season, the amount and quality of observational data, the level of understanding of the underlying processes, and the reliability of their simulation in models. Assigning "low confidence" for projections of a specific extreme neither implies nor excludes the possibility of changes in this extreme. The following assessments of the likelihood and/or confidence of projected changes in weather or climate events are generally for the end of the 21st century, with a reference climate period of 1961-1990. Climate projections for differing emission scenarios[2] generally do not strongly diverge in the coming two to three decades, but uncertainty is large over this time frame due to natural climate variability. For projected changes by the end of the 21st century, either model uncertainty or uncertainty associated with the emission scenario used becomes dominant, depending on the extreme. [3.1.5; 3.2.3]

[INSERT FOOTNOTE 2: Emission scenarios for radiatively important gases result from pathways of socioeconomic and technological development. This report uses a subset of the 40 scenarios extending to year 2100 that are described in the IPCC Special Report on Emission Scenarios (SRES). None of the scenarios includes initiatives explicitly addressing climate change.]

It is *virtually certain*, on the global scale and in most regions, that the frequency of hot temperature extremes will increase, and that the frequency of cold temperature extremes will decrease. A one-in-twenty year annual hottest day is *likely* to become a one-in-two year annual extreme by the end of the 21st century in most regions, except in the high latitudes of the northern hemisphere where it is *likely* to become a one-in-five year annual extreme. It is *very likely* that the length, frequency and/or intensity of heatwaves will continue to increase on the global scale. Moderate (cold and warm) temperature extremes on land are projected to warm faster than global annual mean temperature in many regions and seasons. See Figure SPM.1a. [3.3.1]

[INSERT FIGURE SPM.1A HERE:
Figure SPM.1a: Left (yellow) plot -- Projected changes (in degrees C) in 20-year return values of annual maximum of the daily maximum temperature. Right (blue) plot – Projected return period (in years) for late-twentieth-century 20-year return values of annual maximum of the daily maximum temperature. The bar plots (see legend for more info) show results for regionally averaged projections for two time horizons, 2045 to 2065 and 2081 to 2100, as compared to the late-twentieth-century, and for three different SRES emission scenarios. Results are based on 14 GCMs contributing to the CMIP3 (adapted from Kharin et al., 2007). [3.3.1] See Figure 3.2 for defined extent of regions.]

The frequency of heavy precipitation (or proportion of total rainfall from heavy falls) is *likely* to increase over many areas of the globe in the 21st century, in particular in the high latitudes and tropical regions, and in winter in the northern mid latitudes. For a range of emission scenarios (SRES B1, A1B, A2), a one-in-twenty year annual maximum 24-hour precipitation rate is *likely* to become a one-in-five to one-in-fifteen year event by the end of 21st century in many regions. See Figure SPM.1b. [3.3.2]

[INSERT FIGURE SPM.1B HERE:
Figure SPM.1B: Figure SPM.1b: Left (yellow) plot – Projected changes (relative %) in 20-year return values of annual maximum 24-hour precipitation rates. Right (blue) plot – Projected return period (in years) for late-twentieth-century 20-year return values of annual maximum 24-hour precipitation rates. The bar plots (see legend for more

info) show results for regionally averaged projections for two time horizons, 2045 to 2065 and 2081 to 2100, as compared to the late-twentieth-century, and for three different SRES emission scenarios. Results are based on 14 GCMs contributing to the CMIP3 (adapted from Kharin et al., 2007). [3.3.2] See Figure 3.2 for defined extent of regions.]

It is *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, but there is *medium confidence* that the frequency of the most intense cyclones will increase in some ocean basins. Based on consistency among models and physical reasoning, it is *likely* that tropical-cyclone-related rainfall rates will increase. It is *likely* that mean tropical cyclone maximum wind speed will increase, although increases may not occur in all tropical regions. [3.4.4]

A reduction in the number of mid-latitude storms averaged over each hemisphere due to future anthropogenic climate change is *about as likely as not* and models show large regional changes in cyclone activity, but there is *low confidence* in the detailed geographical projections. Confidence in a projected poleward shift of mid-latitude storm tracks due to future anthropogenic climate change is *medium*. [3.4.5]

There is *medium confidence* that droughts will intensify in the 21st century in some seasons and areas, due either to an enhanced precipitation deficit or to evapotranspiration excess. Confidence is limited because of inconsistent projections of the sign of changes of drought indicators in several regions and between models. There is *medium confidence* that regions that will be affected by an intensification of drought at the end of the 21st century include the Mediterranean, Central Europe, Central North America, and southern Africa. See Figure SPM.2. [3.5.1]

[INSERT FIGURE SPM.2 HERE:
Figure SPM.2: Projected seasonal changes (December, January, February DJF, upper row; and June, July, August, JJA, lower row) of two dryness indices. Left column: Number of consecutive dry days (CDD, days with precipitation < 1mm) expressed in standard deviation from the climatology. Right column: Average soil moisture expressed in kg/m^2. Results are based on multi-model means from CMIP3 projections and expressed as changes of the decadal means, i.e., 2080-2100 mean minus 1980-2000 mean under emission scenario A2 relative to "20th Century Climate in Coupled Model" (20C3M) simulations. Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].]

The magnitude and even the sign of any anthropogenic influence on global patterns of floods are uncertain, and thus there is *low confidence* in projected changes. Nevertheless, an increase in the magnitude and/or frequency of rain-generated floods is anticipated in some catchments and regions where short-term (e.g., daily) rainfall extremes and/or long-term (e.g., monthly, wet-season total) rainfall extremes are projected to increase. Earlier spring peak flows in snowmelt and glacier-fed rivers are *very likely*. [3.5.2]

There is *low confidence* in projections of changes in monsoons (rainfall and circulation), and ENSO (variability and frequency), which are changes in climate phenomena that may affect the frequency and intensity of extremes in several regions simultaneously. Land use changes and aerosols from biomass burning appear to influence monsoons, but these effects are associated with large uncertainties. 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, and so there is *low confidence* in projections of changes in the characteristics of this phenomenon. [3.4.1; 3.4.2]

Mean sea level rise will *very likely* contribute to upward trends in extreme sea levels in the future. Future changes to significant wave height are *likely* to be caused by future changes in storminess and associated patterns of wind change. [3.5.3; 3.5.4]

In most regions, the severity of impacts of heatwaves, wildfires, droughts, and floods (fluvial and coastal) is projected to increase, while changes in cyclone impacts are uncertain. There will be considerable regional variation in the severity of impacts due to differences in exposure, vulnerability, and adaptive capacity. [4.3.4; 4.4; 4.5]

Projections based on unchanging exposure and vulnerability suggest that impacts of weather- and climate-related disasters will increase with climate change. However, confidence in these projections is *low* because they infrequently include changes in non-climatic factors, exposure, and vulnerability. Projected future weather- and climate-related loss studies mostly focus on tropical cyclones in the US and floods in Europe and the US, although some studies have addressed flash floods and hail damage. For the studies that do consider socioeconomic change as well as climate change, there is *medium agreement* but *limited evidence* that the expected changes in exposure are at least as large as the effects of climate change. Indirect and intangible losses are rarely addressed. [4.6.3]

D. CURRENT KNOWLEDGE OF MANAGING THE RISKS OF EXTREME EVENTS AND DISASTERS

Current disaster risk management and climate change adaptation policies and measures have not been sufficient to avoid and fully prepare for and respond to extreme weather and climate events. Improvements in disaster risk management have not kept pace with non-climatic trends that increase vulnerability and exposure, including more people and infrastructure in harm's way. Gaps in national and local public policies and suboptimal risk management at multiple scales have increased disaster risk. [5.2; 6.2.1; 6.3.1; 6.3.2; 6.3.3]

Advances in disaster risk management offer lessons for adapting to climate change. Managing disaster risk involves a continuum of complimentary actions and policy options, including measures to manage uncertainty, reduce risk, transfer and share residual risk, and prepare for and respond to disaster impacts. The relative emphasis placed on different actors and actions depends on the scale of potential impacts, the capacities of governments or agencies to act, the comparative advantage of community based organizations, the level of certainty about the future, the timeframes associated with predictions, and the costs and political consequences of decisions. Lessons learned include [1.1; 1.3; 5.1; 5.3; 5.5; 6.2; 6.3, 6.4]:

- Systematically managing risk is enhanced when policies and measures are coordinated across sectors and scales from local to global, led by organizations at the highest political level, and integrated into economic development and environmental management efforts.
- Legislation supporting managing disaster risks is more effective when regulations are clear and effectively enforced and are complemented by sectoral development and management legislation that explicitly integrates risk considerations.
- Making informed decisions about which policy options to pursue strongly depends on comprehensive databases of observations, losses, and forecasts, on inventories of assets and socioeconomic information, and on the capacity for risk assessment and management.
- Ecosystem-based investments, including conservation measures associated with forestry, land use, coastal wetlands, and biodiversity, help reduce disaster risk across multiple sectors, as well as providing livelihood benefits.
- Effectiveness of early warning systems depends on four interacting components: generation and management of risk knowledge such as monitoring and forecasting, surveillance and warning services, dissemination and communication, and response capability.

Whether or not disaster risk management specifically incorporates climate change, disaster risk management is an important component of adaptation. Successfully managing the risks of existing extreme events, while at the same time not exacerbating future vulnerability, involves anticipating and reducing exposure and vulnerabilities, evaluating the consequences of potential management responses, incorporating uncertainty into planning and implementation, and emphasizing opportunities for learning, flexibility, and innovation. However, institutional separation between disaster risk management and adaptation policy and practice impedes synergy and cooperation. [1.1; 1.3; 1.4; 6.3; 6.4]

Effective disaster risk management and climate change adaptation incorporate a portfolio of strategies, policies, and measures that address exposure and vulnerability within the context of multiple stressors. Managing extreme weather and climate events without considering other stresses and processes may lead to suboptimal strategies and trade-offs. In the absence of comprehensive, multi-stressor analyses, measures implemented to reduce one risk can amplify other stresses (e.g., demographic change and urbanization, pressure on land availability, socio-economic trends, and resource constraints). [5.2; 5.3; 5.4; 5.5.3; 6.2]

Climate change adaptation cannot be effectively pursued without understanding the diverse ways that social processes contribute to the creation and/or reduction of disaster risk. In many cases, disaster risk is causally related to ongoing, chronic, or persistent environmental, economic, and/or social risk factors. Policies and measures affecting quality of life, livelihoods, infrastructure, and natural resource management benefit from integrating disaster risk management and climate change adaptation. [1.1; 2.8; 2.9; 5.3, 6.4]

Many factors determine the penetration of new technologies into disaster risk management and climate change adaptation, particularly in developing countries, including the presence of appropriate and effective institutions, the skill base in the recipient countries, appropriate market conditions, appreciation and implementation of quality control, the availability of spare parts, and an assured supply of basic services such as electricity and water. Often interconnected socioeconomic, institutional, and governance issues determine the degree of success of technology transfer, rather than the technologies themselves. [7.4.3]

Pre-disaster financial mechanisms (including remittances, novel forms of insurance such as index-based micro-insurance, and catastrophe bonds) are important components of disaster risk management and climate change adaptation in regions with little formal insurance or post-event government compensation. The international community, including international financial institutions, non-government organizations, the private sector, and development organizations, is working towards making these mechanisms feasible, affordable, and effective in developing countries, often in the form of public-private partnerships. Adaptation funding could play an additional role in supporting these mechanisms and linking them with pre-disaster risk reduction measures. [5.5.2; 6.3.1; 6.3.3.3; 7.4.4]

E. AVOIDING, PREPARING FOR, AND RESPONDING TO CHANGING DISASTER RISKS AND EXTREMES

Integrated approaches to the assessment and understanding of risk provide the foundation for actions to avoid, prepare for, and respond to extreme weather and climate events and disasters. Risk assessment methods and tools depend on management context, access to data and technology, and stakeholder involvement; these methods vary from formalized probabilistic risk assessment to more qualitative, community-based, participatory assessment schemes. Important elements for risk assessments include recognition of the likelihood and magnitude of extreme events and their impacts, of uncertainties associated with projections, of asymmetric reactions to gains and losses, of differences in coping capacity, and of the influence of cultural worldviews and preconceptions. Because values and beliefs drive perceptions of risk and may be influenced by motivational factors, effective risk communication exchanges, integrates, and shares knowledge about climate-related risks with all stakeholder groups. [1.3; 5.1.5; 5.3.2; 5.4.1; 5.5.1; 6.3.3]

Effective risk management is iterative; accounts for climate change and dynamic trends in exposure and vulnerability; includes regular assessment of the effectiveness of risk prevention, reduction, and response policies and measures; and makes adjustments to maintain and increase effectiveness under changing conditions. Iterative risk management is not a finite set of actions, but is instead an ongoing process of reducing exposure and vulnerability to extreme events, evolving in the context of sustainable development. Management approaches affect current and future exposure and vulnerability, from fostering resilience and sustainable development to inadvertently increasing maladaptation. Principles include mainstreaming disaster risk management into policies and practices; addressing social welfare, quality of life, infrastructure, and livelihoods; and incorporating a multi-hazards approach into planning and action. Iteratively managing risks involves overcoming a multitude of barriers and emphasizing opportunities for learning, flexibility, and innovation. [5.2; 5.4; 5.6; 5.5.3; 6.3.1; 6.3.3; 6.4.2; 8.3.2; 8.3.3; 8.6.3.2; 8.7]

Strategies for improving local disaster risk reduction and climate change adaptation increase resilience when they integrate national and sub-national planning and coordination with knowledge of local conditions and

experiences, supporting local empowerment and collective action. Action at one level of governance can affect other levels, and the resulting interactions among national and sub-national governments, private sectors, and communities can either enhance or constrain risk management. Because there is a strong and complex link between local livelihood security and extreme events, building sustainable livelihoods is an important adaptation to climate change at the local level. [5.1; 5.3; 6.2; 6.3; 6.4]

Integration of disaster risk reduction and climate change adaptation into national development provides the foundation for strategic shifts in managing changing vulnerability and climate risks. An important component is aligning the different roles of national and sub-national governments, private sectors, and communities. National-scale approaches for reducing vulnerability include a range of policy instruments: actions to promote human development, secure livelihoods, and reduce poverty; investments in natural capital and ecosystem-based adaptation; integrated land and water use and development planning, along with appropriate technological and infrastructure approaches; early warning systems; improved engagement with bi-lateral and multi-lateral agencies; and, in the case of developing countries, improved aid effectiveness. [6.3; 6.4]

International policy frameworks and coordination mechanisms have begun incorporating and integrating disaster risk management and climate change adaptation. However, there is less effective integration in operational support for national or local level action. The decisions and the coordination mechanisms of the Hyogo Framework for Action and the UNFCCC explicitly recognize the inter-linkages of disaster risk management and climate change adaptation. However, independent evaluations highlight weaknesses in sustained and effective international support to local level implementation. [7.3]

Synergies in international financing support for disaster risk management and climate change adaptation have yet to be achieved. International funding for disaster risk management remains low compared with spending on post-disaster humanitarian response. Governments have committed to establish much larger funding streams for climate change adaptation, which also could support the longer-term investments necessary for disaster risk management. Achieving this goal relies on donors meeting their funding commitments, improvements in current disbursement procedures, and careful management to ensure responsiveness to the overall goals of disaster risk management and climate change adaptation. Such international efforts, combined with national-level integration of disaster risk reduction and climate change adaptation, have the potential to produce synergistic outcomes in resilience [6.4.4; 7.4.2]

Observed and projected trends in exposure, vulnerability, and extreme events can provide guidance in designing risk management and adaptation strategies, policies, and measures. The importance of these trends for decision making depends on their magnitude and degree of certainty at the temporal and spatial scale of the risk being managed and on the available capacity to implement risk management options. Table SPM.1 provides illustrative examples of how adaptation and risk management decisions can be informed by trends in vulnerability, exposure, and extreme events. Trends are provided at the scale relevant to decision making in each example. Trends in extreme events are also provided at global and regional scales to illustrate that the direction, magnitude, and/or degree of certainty for trends may differ at these scales.

When there is a high degree of certainty about trends in extreme events at a scale relevant to adaptation and risk management decisions, projections of extreme events can inform adjustments in strategies, policies, and measures, such as adjustments in infrastructure design. A high degree of certainty about trends in extreme events may not exist at local and national scales of decision making; at these scales, there may be a higher degree of certainty about trends in exposure and vulnerability. The certainty about trends in extreme events at different scales depends on the type of extreme event, its spatial extent, and its dependence on non-climatic factors such as land use patterns. Although regional and global trends in extreme events imply some probability of events occurring at smaller scales, confidence in projected trends at smaller scales is often more limited. Using global and regional trends in extreme events to inform risk management when there is a low degree of certainty in trends at the scale of risk management may lead to strategies, policies, and measures that do not effectively manage risk. A more robust approach is to focus on low-regrets risk management options that reduce exposure and vulnerability across a range of outcomes, including measures to manage residual risk such as early warning and risk transfer. [2.5.4.2; 2.7.2; 2.7.4.1; 3.2.3; 4.2.5; 4.3.1; 4.4.5.1; 4.5.4; 6.3.1.3; 6.3.2.2; 6.4.2; 9.2.2; 9.2.13]

[INSERT TABLE SPM.1 HERE
Table SPM.1 provides illustrative examples of how adaptation and risk management decisions can be informed by information on trends in exposure, vulnerability, and extreme weather and climate events. Trends are provided at the scale relevant to decision making in each example. Trends in extreme events are also provided at global and regional scales to illustrate that the direction, magnitude, and/or degree of certainty for trends may differ at these scales.]

Evidence of the economic efficiency of specific adaptation approaches remains limited and fragmented. Although cost-benefit analyses are often used to estimate economic efficiency, their applicability for evaluations of adaptation appears limited. In some cases, a cost-effectiveness evaluation is preferable, involving the selection of options with the lowest cost for reaching a given objective. In other cases, risk-based approaches assessing whether policies achieve an acceptable level of risk are more useful. [4.6.2; 4.6.4; 5.4.2; 6.3.3; 6.4.1]

The costs of enhancing disaster risk management and climate change adaptation to address changing risks are difficult to assess, with most studies focusing on sea level rise and slower onset impacts on agriculture. Assessments of the costs of adaptation infrequently distinguish extreme events from gradual change, or they treat extreme events as similar to gradual onset phenomena with deterministic impact metrics**.** Estimates of the costs of adaptation globally range from 4 to 100 billion USD per year, with a bias towards the higher end of costs, but *confidence* remains *low*. These estimates significantly underestimate costs because sectors such as ecosystem services, energy, manufacturing, retailing, and tourism are excluded and because the adaptation cost estimates assume low levels of investment. These estimates also do not consider remaining, unavoidable residual damages. [4.6.2; 4.6.4; 6.4.1]

F. IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT

Transformational changes in socio-ecological systems can influence the capacity of societies to adapt to changes in extreme weather and climate events (*medium agreement, limited evidence*). In some cases and in some locations, changes in extreme events will complicate the prospects for adaptation unless anticipatory action is taken. Transformations, defined as fundamental qualitative changes or changes in composition or structure (see Box SPM.2), can be planned and anticipated, or reactive and forced. Deliberate transformations frequently involve adaptive management, learning, innovation, and leadership (*medium evidence*). [8.3.2; 8.5.2; 8.6.3]

_____ START BOX SPM.2 HERE _____

Box SPM.2: Transformations

Disaster risk management and climate adaptation strategies can contribute to sustainable development, but the success of such strategies in the context of climate extremes and a changing risk landscape will be, in some cases, dependent upon transformational changes, as contrasted with incremental change or business as usual. Transformation often involves a change in mindsets, mental models, assumptions, beliefs, priorities, and loyalties, which can be prerequisites to changes in systems and structures. Adaptive management, learning, innovation, and leadership can facilitate transformation through trust building among stakeholders and a willingness to experiment and move beyond rigid agendas and practices to take on new information, new challenges, and new ways of operating. The transformation of socio-technical systems can potentially facilitate transitions from established systems to sustainable systems. [8.6.2]

_____ END BOX SPM.2 HERE _____

Addressing the underlying causes of vulnerability, as well as the structural inequalities that create and sustain poverty and constrain access to resources, is an important prerequisite for sustainability (*high agreement, robust evidence*). This involves integrating disaster risk reduction with other social and economic policy areas, as well as a long-term commitment to managing risk (*medium evidence*). [8.7]

Resilience-based approaches provide insights and tools for dealing with disturbances and surprises. These approaches include, for example, building institutional capacity and adaptive organizations, such as in hospitals or in the humanitarian sector, and enhancing the range and diversity of ecosystems responses to extreme events by reducing non-climatic stresses on coral reefs and rainforests (to increase their ability to buffer impacts of climate change). [6.4.2; 8.3.3; Box 8.2].

Short-term and long-term perspectives on both disaster risk reduction and climate change adaptation are often difficult to reconcile (*high agreement, robust evidence*). There are recognized tensions, trade-offs, and potential conflicts between different values, interests, objectives, and visions for the future. Resilience thinking offers some tools for reconciling short-term and long-term responses, including integration of different types of knowledge, an emphasis on inclusive governance, and principles of adaptive management. However, there is no single approach or development pathway for managing the risks of extreme events. [8.3.1; 8.3.3; 8.7]

Climate-related disasters generate both losers and winners, with long-term implications for human security (*medium agreement, robust evidence*). The outcomes are closely linked to existing capacities and resources that reflect patterns of development. Social thresholds and tipping points may pose limits to a sustainable and resilient future (*low agreement, limited evidence*). [8.4.3; 8.5.1; 8.5.3; 8.5.4]

Progress toward sustainable development benefits from leadership that questions mindsets, assumptions, and paradigms and that encourages innovation and the generation of new patterns of response (*medium agreement, medium evidence*). Responding successfully to multiple stressors, including disaster risk, often involves broad participation in strategy development, the capacity to combine multiple perspectives and differing worldviews, and contrasting ways of organizing social relations [8.2.5; 8.6.3; 8.7].

A wide range of technological innovations is being explored to facilitate risk reduction and risk enhancement (*high agreement, robust evidence*). The transformation of society towards sustainability and resilience involves both social innovations and technological innovations, incremental as well as radical. Although there is much uncertainty about the future, there is *medium evidence* that adding an anticipatory dimension to planning and decision making can build resilience. [8.2.2; 8.2.3]

There is *high confidence* that integrated disaster risk management and climate change adaptation, through reduction of exposure and vulnerability, significantly reduce impacts from extreme events, including economic losses, morbidity, and mortality. [1.1; 1.3; 5.2; 5.4; 5.5.3; 6.3]

_____ START BOX SPM.3 HERE _____

Box SPM.3: Treatment of Uncertainty

Based on the Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties,[3] this Summary for Policymakers relies on two metrics for communicating the degree of certainty in key findings:

- Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively.
- Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment).

[INSERT FOOTNOTE 3: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe, and F.W. Zwiers, 2010: *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*. Intergovernmental Panel on Climate Change (IPCC). Available at <http://www.ipcc.ch>.]

Key findings are based on the evaluation of associated evidence and agreement. Depending on the nature of the evidence evaluated, uncertainty may be quantified probabilistically. In most cases, either a quantified measure of uncertainty or an assigned level of confidence is presented.

The following summary terms are used to describe the available evidence: "limited," "medium," or "robust"; and for the degree of agreement: "low," "medium," or "high." A level of *confidence* is expressed using five qualifiers "very low," "low," "medium," "high," and "very high." It synthesizes the author teams' judgments about the validity of findings as determined through evaluation of evidence and agreement (Box SPM.3 Figure 1).

[INSERT BOX SPM.3 FIGURE 1 HERE:
Box SPM.3 Figure 1: A depiction of evidence and agreement statements and their relationship to confidence. Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence.

The following terms have been used to indicate the assessed likelihood:

Term*	**Likelihood of the outcome**
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33 to 66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

* Additional terms that were used in limited circumstances in the AR4 (*extremely likely* – 95-100% probability, *more likely than not* – >50-100% probability, and *extremely unlikely* – 0-5% probability) may also be used in the AR5 when appropriate.

Table SPM.1. Table SPM.1 provides illustrative examples of how adaptation and risk management decisions can be informed by information on trends in exposure, vulnerability, and extreme weather and climate events. Trends are provided at the scale relevant to decision making in each example. Trends in extreme events are also provided at global and regional scales to illustrate that the direction, magnitude, and/or degree of certainty for trends may differ at these scales.

		Observed and Projected Trends in Extreme Events Type Across Spatial Scales			
Issue of concern	**Trend in aggregate vulnerability and exposure at scale of risk management in example region**	**Global observed (since 1950) and projected (to 2100) trend in extreme event type**	**Observed (since 1950) and projected (to 2100) trend in extreme event type in example region**	**Observed and projected trend in extreme event type at scale of risk management in example region**	**Risk management/adaptation options**
Public health concerns about increasing mortality and morbidity due to **heatwaves in an urban area** in Western Europe	Factors affecting vulnerability and exposure include age (old and young); pre-existing health conditions including certain chronic diseases; body-mass index; outdoor work; clothing choices; access to and use of cooling (partly related to the risk of power failures during heatwaves, which also depends on electricity generation and transmission systems); urban infrastructure; and socioeconomic factors including poverty, crime levels, and social isolation. Trends in these factors may increase vulnerability and/or exposure, including an aging population, the loss of urban green space, and the increase of urban heat island effects due to planned and unplanned urbanization. [2.5.4.2; 2.7.2; 2.7.4.1; 4.3.1; 4.4.5.1; 4.5.4; 9.2.2]	Observed: *Likely* increase in warm spells, including heatwaves, in most regions. Projected: *Very likely* increase in length, frequency, and/or intensity of warm spells, including heatwaves over most land areas. [Table 3.1; 3.3.1]	Observed: *Medium confidence* in increase in heatwaves in Europe. Projected: *High confidence* in *likely* increase in heatwave duration in Europe [Table 3.2; Table 3.3; 3.3.1]	Observations and projections can provide information about observed trends and projections of hot days and heatwaves in specific urban areas (because most urban areas in the region can expect increased heatwaves due to both regional trends and additional urban heat island effects).	Low-regrets options that reduce vulnerability and exposure across a range of trends in heatwaves: • early warning systems • public information on what to do during heatwaves; emergency hotlines • community sensitization, warning systems, and home caretaking • installation of air conditioning, for instance in elderly homes and schools • use of social networks to reach vulnerable elderly Specific adjustments in strategies, policies, and measures informed by trends in heatwaves: • awareness raising (for general public and relevant authorities and organizations) of rising risk that people may not be aware of, particularly in cities where in the past heatwaves occurred at very low frequency • changes in building design and urban land use planning • changes in standards for cooling capacity, particularly of public facilities and critical infrastructure • adjustments in energy generation and transmission infrastructure Increasing disaster risk due to climate change suggests higher prioritization of heatwaves as a public health concern, particularly in cities not considered at risk in the past. [6.3.1.3; 9.2.2]
Increasing **losses from hurricanes** in the USA and the Caribbean	*High confidence* that exposure of people and economic assets is increasing, and *very likely* that this is the major cause of the long-term changes in disaster losses.	Observed*:* *Low confidence* of any robust long-term increases in tropical cyclone activity, after accounting for changes in observing capabilities. Projected: *Unlikely* increase in global frequency of tropical	Observed: Observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, but *low confidence* that any long-	Limited model capability to project changes with resolution relevant to specific settlements or other locations.	Low-regrets options that reduce vulnerability and exposure across a range of trends in hurricanes: • Early warning systems • Integration of seasonal forecasts with projections of the upcoming hurricane season's possible activity • Regional risk pooling reducing financial exposure

Table SPM.1 continued

		Observed and Projected Trends in Extreme Events Type Across Spatial Scales			
[4.2.5]	[4.2.5]	cyclones (*likely* decrease or no change). *Likely* increase in mean maximum wind speed, but possibly not in all basins. *Likely* increase in tropical cyclone-related rainfall rates. Projected sea level rise *likely* to further compound tropical cyclone surge impacts. [Table 3.1; 3.4.4]	term observed increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities. <u>Projected</u>: *Medium confidence* that the frequency of the most intense cyclones will increase in some ocean basins [3.4.4]		For hurricane risk, climate information is too uncertain and imprecise to justify large-scale adjustments in strategies, policies, and measures (except for adjustments to long-term coastal infrastructure given possible changes in storm surge levels primarily driven by sea level rise). Instead, in this context of high underlying variability, adaptive management involving learning becomes even more important, such as: • Improving localized climate and risk information • Emphasizing adaptive management for authorities managing risk in terms of flexibility, learning, and responsive governance The Cayman Islands National Hurricane Committee provides an example of a learning-based organization. [6.4.2] [6.3.1.3; 9.2.13]
Flash floods in Nairobi's informal settlements	*High confidence* of increases as Nairobi experienced high impact flooding in last decade. Rapid expansion of poor people living in informal settlements around Nairobi has led to houses of weak building materials being constructed immediately adjacent to rivers and to a lack of natural drainage areas, increasing rapid run-off and exposing more people. [6.3.2.2]	<u>*Observed*</u>: *Low confidence* in changes in the magnitude and frequency of floods at the global level. AND *Likely* statistically significant increases in the number of heavy precipitation events in more regions than there have been statistically significant decreases, but with strong regional and subregional variations in the trends. <u>*Projected*</u> *Low confidence* in global projections of changes in flood magnitude and frequency because of insufficient literature and poor agreement between models. BUT Increase in magnitude and/or frequency anticipated in regions where rainfall extremes are projected to increase. AND *Likely* increase in frequency of heavy precipitation events (or increase in proportion of total rainfall from heavy falls) over many areas of the globe, in particular in the high latitudes and tropical regions, and in winter in the northern mid latitudes. [Table 3.1; 3.3.2; 3.5.2]	<u>Observed</u>: Inconsistent patterns in existing studies of heavy precipitation across Africa. In East Africa, *medium confidence* of an observed decrease in heavy precipitation. <u>Projected:</u> *Very likely* increase in heavy precipitation in East Africa. *High confidence* in *likely* increase in heavy precipitation days and contribution to annual totals. [Table 3.2; Table 3.3; 3.3.2]	Limited ability to provide quantified local flood projections, partly due to lack of fine-scale climate projections, but also due to lack of knowledge of changes in local hydrology.	While it is difficult to directly link increased heavy precipitation to more severe flooding, the upward trend of aggregate exposure and vulnerability increases the need to reduce exposure and vulnerability even without a strong climate signal. Examples of such "no or low regrets" measures include strengthening building control regulation, focused poverty reduction schemes and city-wide drainage and sewerage improvements. More specific climate-related disaster risk reduction measures include the involvement of poor people in decision-making processes with the potential of developing "cash-for-work" programs to install riparian buffers, canals, drainage channels, and trenches between structures. Climate change is specifically mentioned in the African Development Bank sponsored Nairobi Rivers Rehabilitation and Sewerage Improvement project, and addressed through investments in: • tree planting in riparian areas • attention to climate variability and change in the choice of location and design of wastewater infrastructure • environmental monitoring plan that includes river flow monitoring to enable early predictions of floods and drought [6.3.1.3; 6.3.2.2]

Figure SPM.1a (Modified from Figures 3.6 and 3.8).

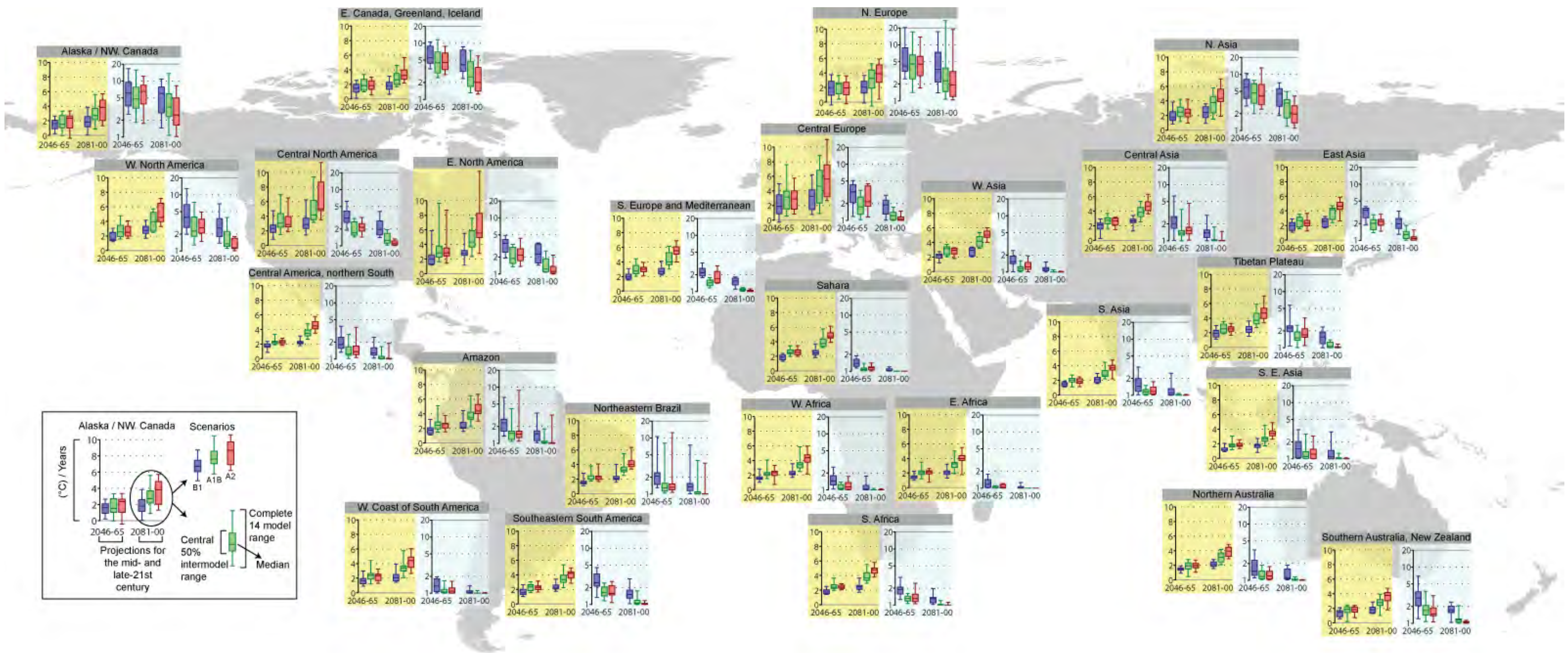


Figure SPM.1a: Left (yellow) plot -- Projected changes (in degrees C) in 20-year return values of annual maximum of the daily maximum temperature. Right (blue) plot – Projected return period (in years) for late-twentieth-century 20-year return values of annual maximum of the daily maximum temperature. The bar plots (see legend for more info) show results for regionally averaged projections for two time horizons, 2045 to 2065 and 2081 to 2100, as compared to the late-twentieth-century, and for three different SRES emission scenarios. Results are based on 14 GCMs contributing to the CMIP3 (adapted from Kharin et al., 2007). [3.3.1] See Figure 3.2 for defined extent of regions.

Figure SPM.1b (Modified from Figures 3.6 and 3.8).

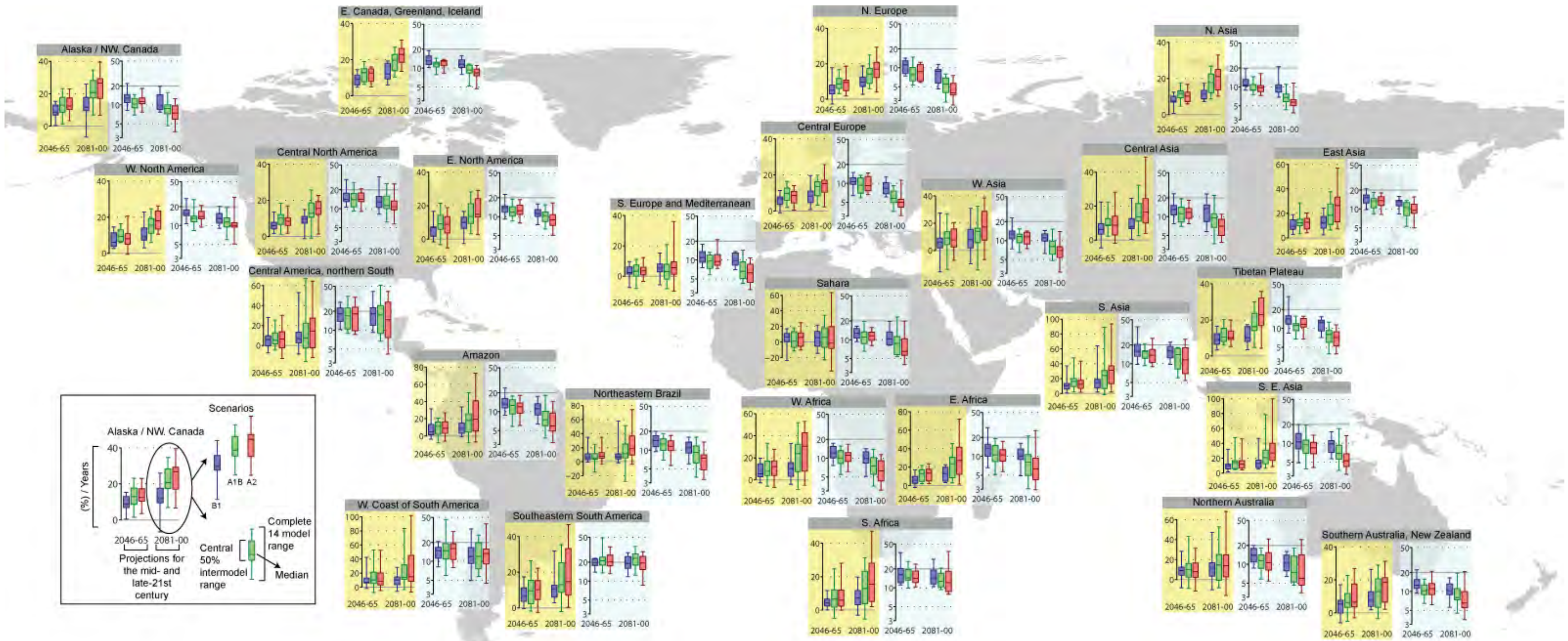


Figure SPM.1b: Left (yellow) plot – Projected changes (relative %) in 20-year return values of annual maximum 24-hour precipitation rates. Right (blue) plot – Projected return period (in years) for late-twentieth-century 20-year return values of annual maximum 24-hour precipitation rates. The bar plots (see legend for more info) show results for regionally averaged projections for two time horizons, 2045 to 2065 and 2081 to 2100, as compared to the late-twentieth-century, and for three different SRES emission scenarios. Results are based on 14 GCMs contributing to the CMIP3 (adapted from Kharin et al., 2007). [3.3.2] See Figure 3.2 for defined extent of regions.

Figure SPM.2 (Modified from Figure 3.10).

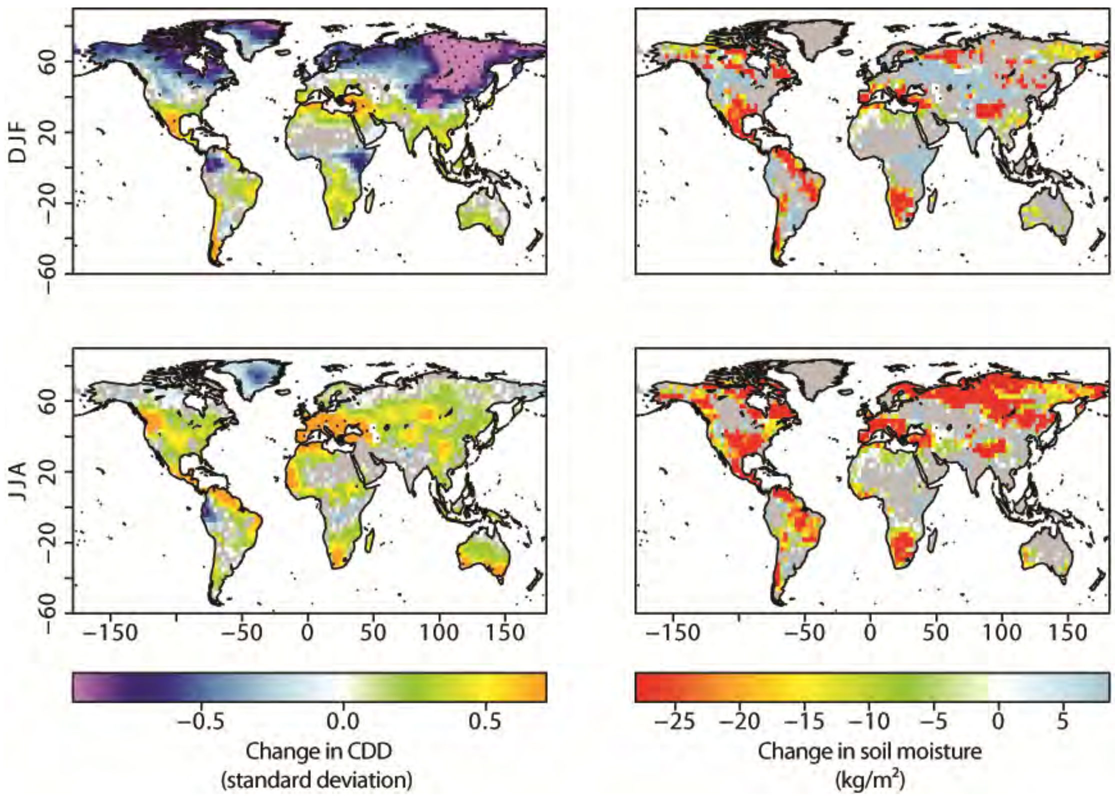
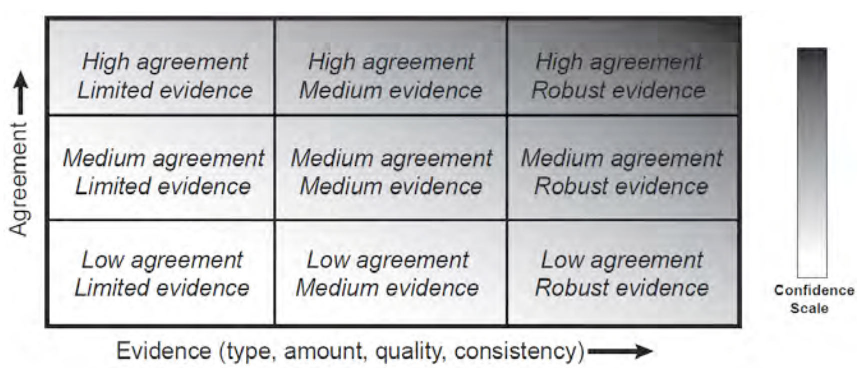


Figure SPM.2: Projected seasonal changes (December, January, February DJF, upper row; and June, July, August, JJA, lower row) of two dryness indices. Left column: Number of consecutive dry days (CDD, days with precipitation < 1mm) expressed in standard deviation from the climatology. Right column: Average soil moisture expressed in kg/m^2. Results are based on multi-model means from CMIP3 projections and expressed as changes of the decadal means, i.e., 2080-2100 mean minus 1980-2000 mean under emission scenario A2 relative to "20th Century Climate in Coupled Model" (20C3M) simulations. Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].



Box SPM.3 Figure 1: A depiction of evidence and agreement statements and their relationship to confidence. Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence.

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

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Contents

Executive Summary

This assessment report examines the challenge presented by the management of extreme events and disasters in the context of anthropogenic climate change, with the goal of providing guidance for advancing climate change adaptation. This effort integrates knowledge developed and employed by the disaster risk management community. Climate change adaptation and disaster risk management seek to inform climate-related decisions and reduce disaster risk, thus supporting and promoting sustainability in social and economic development.

Anthropogenic climate change is expected to shift the distribution of climate and weather characteristics (temperature, precipitation, wind, sea level, etc.), driving changes in spatial and temporal averages and the frequency, magnitude, and character of extreme physical events [1.2, Chapter 3]. Physical extremes occur at a variety of temporal and spatial scales. Depending on timing and geographic location, gradual climate changes may result in the crossing of thresholds that enhance extreme events.

When extreme events involve *extreme direct and indirect social and economic impacts* leading to a severe disruption of the normal, routine functioning of the affected society, they contribute to the occurrence of "disaster". Extreme impacts and disasters may arise from non-extreme events, while extreme events often may not lead to extreme impacts [1.2, Chapter 4]. Disaster may arise from lesser physical events in the presence of physical and ecological conditions that affect human welfare and security and social vulnerability, short-duration events superimposed onto a gradual trend, the presence of multiple hazards, or the timing of extreme events. The relative importance of different types of physical events, of events not previously experienced in particular locales, and uncertainty in each of these characteristics will change over time, as will vulnerability and exposure**.**

Climate change adaptation cannot be effectively pursued without understanding the diverse ways in which social processes contribute to the construction and reduction of disaster risk [1.1, Chapter 2]. Disasters are predicated on the existence of vulnerability, which can be exacerbated by social processes and/or events [Chapter 2]. Disaster risk is often causally related to ongoing, chronic or persistent environmental, economic or social risk factors. Poverty is generally, but not always, associated with increases in vulnerability [chapter 2]. This complicates disaster risk prevention and reduction efforts. The reduction of, or response to, extreme impacts is often complicated by the lack of reliable and timely information on disaster risk.

Risk assessment is a starting point for climate change adaptation and disaster risk reduction and transfer. The assessment and analysis process may employ a variety of tools according to management context, access to data and technology, and stakeholders involved [1.3]. These tools will vary from formalized and sophisticated probabilistic risk analysis to more labour intensive, qualitative schemes. Any form of risk assessment must confront difficulties in estimating the likelihood and magnitude of extreme events and their impacts [1.2, 1.3]. Effective risk communication requires exchanging, sharing, and integrating knowledge about climate-related risks among all stakeholder groups. Among individual stakeholders and groups, perceptions of risk are driven by psychological and cultural factors, values, and beliefs.

Learning to manage uncertainty and dynamic complexity is central to climate change adaptation, which can be seen as a process of shifting coping ranges in anticipation of future risks [1.4]. Disaster risk management and climate change adaptation offer frameworks for advanced learning processes that may help reduce or avoid a host of barriers which may undermine planned adaptation efforts, or lead to implementation of maladaptive measures. [1.3, 1.4]. Case studies can provide insight into how societies perceive and act on risk, i.e. how they filter the complexity associated with risk assessment and risk management [1.4, chapter 9]. Strategies to adapt to short-timescale climate variability may offer insight into effective information and communication, as well as managerial, technological, and wealth constraints on adaptive efforts. Because of the deep uncertainty and the long timeframe associated with climate change, robust adaptation efforts require iterative risk management strategies [1.3].

Effective risk management involves integrative approaches implemented at multiple spatial, social, and temporal scales [1.1, 1.3]. Although climate risks are location-specific, they are constructed, understood and responded to at the individual household through to the national and international levels, in the context of economic, political, technological, and cultural shifts. Climate change adaptation policy, strategies and interventions will only be successful if the complex interactions between phenomena and actions at local, sub-national, national and international scales are appreciated and anticipated.

The synergic interaction between disaster risk, poverty, degradation of ecosystem services, inappropriate land use planning, and poor governance in some countries suggests that effective interventions would be designed with a composite agenda of development, poverty reduction, climate change adaptation, and disaster risk reduction [1.3]. Such an effort would require a novel level of institutional integration and coordination. Holistic institutional frameworks (for strategy, policy-making, financing) that include development concerns have been shown to be more appropriate in several countries [1.3, Chapter 9]. Historical examples support the mutually reinforcing nature of generic (development) and specific (climate-related) adaptive capacity [1.3].

1.1. Introduction

1.1.1. Purpose and Scope of the Assessment Report

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, 2007a). While specific outcomes of climate change are uncertain, it is *virtually certain* that the frequency, intensity, and variability of extreme and non-extreme climate events, in addition to the mean values of climate variables, will be altered (chapter 3). These alterations are very likely to change the nature and frequency of weather and climate extremes that can contribute to disasters, although this does not necessarily imply only intensification or increases in the number of such events. It is in particular *very likely* that the length, frequency and/or intensity of heatwaves will continue to increase over most land areas, and *likely* that the frequency of heavy precipitation (or proportion of total rainfall from heavy falls) will increase over many areas. If not effectively managed, such changes are *very likely* to lead to an increase in some climate-related disaster risks, and in the number, size and spatial extent of disasters related to these specific extremes. Changes in some other weather and climate extremes, e.g. droughts or tropical cyclones, are more difficult to predict with confidence, but change can still be expected and these will also *very likely* affect disaster risk.. At the same time, climate change may reduce hydrological- and meteorological- related disaster risk in some circumstances (e.g., via a reduction in the number of extremely cold days and nights).

New, improved or strengthened disaster risk reduction processes will undoubtedly be required in many geographical areas affected by climate change. This is all the more important if one considers that disaster risk reduction and adaptation to historical climate variability have not been widely or uniformly successful, as is clearly demonstrated by the consistent, rapid growth in real economic disaster losses and livelihood disruption associated with meteorological and hydrological events over the last 50 years (UN, 2009). This is the case despite important advances in the reduction of loss of life associated with improved early warning systems (UN, 2009). The Hyogo

Framework for Action (UNISDR, 2005), adopted by 168 governments, provides a point of reference to describe disaster risk reduction and its practical implmentation. Subsequent United Nations statements (UNISDR, 2008a; 2009a; 2009b; 2009c) stress the need to move forward with a closer integration of disaster risk reduction and climate change adaptation concerns and goals, all in the context of development.

This report addresses one general and three specific challenges associated with anthropogenic climate change and its effects on extreme events, disaster and disaster risk, disaster risk management and climate change adaptation. The general challenge is to assess why and how the management of extreme events and disasters (based on historical experience and evolution in practice) could be integrated more closely with and contribute to climate change adaptation objectives and processes, in the context of development.

The three specific challenges are:

1) To assess the relevance and utility of the concepts, methods, strategies and instruments employed in the management of climate-associated disaster risk under conditions of historical climate, for future climate change adaptation.
2) To assess the new challenges and requirements that climate change and climate change adaptation brings to the disaster risk management field.
3) To assess the implications of such revisions in the field of disaster risk management for climate change adaptation.

The first section of the present chapter briefly introduces the basic concepts, definitions, contexts and management approaches descibed in this assessment report. Later sections of this chapter define critical aspects of significance to the management challenge, particularly the subjects of extreme events and extreme impacts; disaster risk management, reduction, and transfer; integration with climate change and adaptation processes; and, the notions of coping and adaptation.

This assessment report as a whole is organized into three major parts. 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 part (chapters 5-8) 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, chapter 9 focuses on experience gained from specific instances of extreme impact and disaster, highlighting key conclusions from earlier chapters. These case studies are referred to throughout the other chapters.

1.1.2. Disaster Risk and Disaster: Basic Concepts for Risk Management and Adaptation

1.1.2.1. Key Concepts and Definitions

The "skeleton" definitions of key terms and concepts presented in this chapter take into account a number of existing official glossary definitions (ISO, 2010; IPCC 2007b; IPCC 2007c; UNISDR, 2009d) but also reflect the fact that concepts and definitions evolve as knowledge, needs and contexts vary. Disaster risk management and climate change adaptation are dynamic fields, and will necessarily continue to exhibit an evolution in concepts and definitions of key notions. A glossary which incorporates the basic definitions is provided at the end of this report. In subsequent chapters, variants among these definitions will be examined and considered in detail where necessary. Figure 1-1 provides an schematic representation of the relationships among many of the concepts defined here.

[INSERT FIGURE 1-1 HERE
Figure 1-1: The key concepts and scope of this report. The figure indicates schematically key concepts involved in disaster risk management and climate change adaptation, and the interaction of these with sustainable development.]

Disaster risk is defined for the purposes of this report as the potential for loss or damage to lives, livelihoods, health status, economic and cultural assets, services (including environmental) and infrastructure, which could occur in a community or society due to the effect of particular physical events occurring within some specified future time period. This qualitative statement will be expressed formally later in this assesment (section 1.3 and chapter 2).

Disaster risk reduction is defined as the concept, process and objective of reducing existing, or anticipating new disaster risks through systematic efforts to analyze and manage their causal factors. This includes reducing the exposure to hazards, lessening the vulnerability of people, livelihoods and assets, insuring the appropriate sustainable management of land, water, and other components of the environment, and improving the preparedness for, response to and recovery from the impacts of adverse physical events. Emphasis is on universal concepts involved in the consideration of reducing disaster risks as opposed to the specific management actions and activities for doing so and which are captured under the notion of disaster risk management (see below).

Disaster, the actualization or materialization of disaster risk, is defined as the existence of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread human, material, economic or environmental damage or losses that require immediate emergency response to satisfy critical human needs under conditions of severe stress and which may require external support for recovery.

Climate change adaptation refers to the adjustment in natural systems in response to actual climatic stimuli or their effects, and in human systems, in response to both actual and expected stimuli, such as to moderate harm or exploit beneficial opportunities. This modifies the IPCC (2007b) definition that speaks of the "adjustment in natural and human systems in response to actual and expected climatic stimuli, such as to moderate harm or exploit beneficial opportunities".

Disaster risk management is defined as the systematic process of using administrative directives, organizations and operational skills, abilities and capacities to implement policies, strategies and specific mechanisms which promote increased or improved risk awareness and evaluation, tangible means to reduce disaster risks, disaster response, increased coping capacities and recovery practices, and lessen the potential or actual adverse impacts of physical events on society. In this chapter and report the use of the term **risk management** should be interpreted as being a synonym of disaster risk management, unless otherwise made explicit.

Extreme events are defined by the IPCC (Baede, 2007) as those that are "rare within their statistical reference distribution at a particular place. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called 'extreme weather' may vary from place to place…". In the present assessment (glossary) such events are defined in terms of "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends ("tails") of the range of observed values of the variable. [...] Absolute thresholds (rather than these relative thresholds based on the range of observed values of a variable) can also be used to identify extreme events (e.g., specific critical temperatures for health impacts). [...]" (see section 1.2 and chapter 3 for further discussion of this definition).

Although such events are often associated with disaster (which entails extreme societal impacts), this is not necessarily the case. Non-extreme physical events can also lead to disasters where physical or societal conditions foster this (section 1.1.2 and chapters 2-4). In any one place, the range of disaster-inducing events can increase if social conditions deteriorate. Although the theme of "extreme" climate events and the risk they may signify is a central concern for this assessment, it is the reduction and anticipation of overall disaster risk, including that arising from non-extreme physical events, as well as the overall advancement of adaptation practices, that are the more general concern.

In fact, the vast majority of disasters registered annually in most disaster databases are not associated with extreme events as defined probabilistically (section 1.2 and chapter 3), yet have important, potentially extreme, impacts for local and regional societies in isolation or when they accumulate (UN, 2009; CRED, 2010; Corporación OSSO, 2010). The Desinventar database has been used by UNISDR, the Inter-American Development Bank, and others to examine small and medium scale disaster occurrences and "extensive risk" (the wide scale, accumulative loss and damage caused by the aggregation of many small events) in Latin America and Asia in particular (IDEA, 2005; UN, 2009; Corporación OSSO, 2010).

The definitions of disaster risk and disaster posited above do not include the extreme impacts of climate and hydrological events on ecosystems or the physical earth system per se. In this assessment, such impacts may be relevant to disaster if, among others possibilities: i) they impact livelihoods negatively; ii) they have consequences for global food security; and iii) they have serious impacts on human health.

Extreme physical ecosystem impacts are nevertheless considered in detail in chapter 4 as an important aspect of the impact of and adaptation to extreme events that have significant consequences for human wellbeing. In excluding such impacts from the definition of "disaster" employed here, we are in no way underestimating their broader significance (e.g., their existence value) or suggesting they should not be dealt with under the rubric of adaptation concerns and management needs. Rather, we are establishing their position within the conceptual framework of climate related, socially-defined "disaster and disaster risk" studies and the management options available.

1.1.2.2. Disaster Risk

Climate change adaptation and disaster risk management seek to reduce factors and modify environmental and human contexts that contribute to climate-related disaster risk, thus supporting and promoting sustainability in social and economic development. Given the central importance of the notion of disaster risk, a useful and necessary starting point for conceptual convergence and the promotion of integration is to assure that there is clarity as to the causal factors associated with such risk.

Disaster risk cannot exist without the potential occurrence of damaging physical events. But such events are not in and of themselves sufficient to explain disaster risk or project its potential magnitude.

When physical events, such as tropical cyclones, floods, and drought, can affect exposed elements of human systems in a negative manner, they assume the characteristic of **hazard.** Hazard is the potential occurrence of a natural or human-induced physical event, that can contribute to negative effects such as loss of life, injury or other health impacts, as well as damage and loss to assets, infrastructure, livelihoods, service provision and environmental resources.

Exposure refers to the presence of people, livelihoods, environmental services and resources, economic, social and cultural assets, and infrastructure in areas subject to the occurrence of potentially damaging physical events and which, thereby, are subject to potential future loss and damage. Quantification of such loss depends amongst other things, on the magnitude of an event in a given location. The definition of exposure in this assessment subsumes physical and biological systems under the concept of "environmental services and resources", accepting that these are fundamental for human welfare and security (Gaspar, 2010). Non-geographical exposure can also exist to events at distance in space and/or time from a vulnerable object, for example where food insecurity is encountered as a result of global market changes in part a result of drought, or flood impacts on crop production in another place. In such cases, exposure is not associated with the hazard itself but with the reach of mediating social (in this case largely economic and regulatory) institutions.

Physical events are transposed into **hazards** where social elements (or environmental resources that support human welfare and security) are exposed to their potentially damaging or transforming impacts (Smith, 1996; Tobin and Montz, 1997; Cardona, 1986, 1996, 2010; Lavell, 2003; Wisner *et al.,* 2004), so that hazard should be considered a latent threat rather than the event itself. Risk reduction and adaptation interventions require prior recognition of this latent risk and its social and physical dimensions (ICSU-LAC, 2010).

Under exposed conditions, future loss and damage will be the result of a physical event (or events) interacting with socially constructed conditions denoted as **vulnerability**. Vulnerability**,** when used with reference to human systems, is defined here as the susceptibility or predisposition for loss and damage to human beings and their livelihoods, as well as their physical, social and economic support systems, when affected by physical events. This includes the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist and recover from the impact of a physical event (Wisner *et al.,* 2004). Vulnerability may be evaluated according to a variety of quantitative and qualitative metrics (Schneider *et al.,* 2007; Cardona, 2010). The term **sensitivity** is often used to connote susceptibility in the above context.

Vulnerability is a function of diverse historical, social, economic, political, cultural, institutional, natural resource, and environmental conditions and processes. The concept has been developed as a theme in disaster work since the 1970s (Baird *et al.,* 1975; O'Keefe *et al.,* 1976; Wisner *et al.,* 1977; Gaillard, 2010) and variously modified in different fields and applications in the interim. A detailed discussion of this notion and so called "vulnerability factors" is provided in chapter 2.

The importance of vulnerability to the disaster risk management community may be appreciated in the way it helped reveal the role of 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 the "physicalist" interpretation of disaster).

Geographical exposure as such is not vulnerability, although vulnerability can not exist without exposure and is many times specific to different hazards. Where exposure to potentially damaging physical events is not accompanied by some degree of vulnerability of the exposed social elements, then loss and damage will not ensue. Differential levels of vulnerability will lead to differential levels of damage and loss under similar conditions of exposure to physical events of a given magnitude.

The fundamentally social connotation and "predictive" value of vulnerability is emphasized in the definition used here. The earlier 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" (IPCC, 2007b). The latter definition makes physical causes and their effects an explicit aspect of vulnerability while the social context is encompassed by sensitivity and adaptive capacity (defined later). In the definition used here, the social context is emphasized explicitly, and vulnerability is independent of physical events (O'Brien *et al.,* 2007).

The notion of **mitigation** in the climate change literature refers to the reduction of the rate of climate change and of its causal factors, whereas in disaster risk reduction work it refers to the amelioration of disaster risk or disaster itself through reduction of existing hazards, exposure or vulnerability. This report presumes that mitigation is a substantive action that can be applied in different contexts where attenuation of existing conditions is required. **Disaster risk mitigation** refers to actions that reduce risk prior to event impact; **disaster mitigation** is used to refer to actions that attempt to limit futher adverse conditions once disaster has materialized.

The "negative" concept of vulnerability has been contrasted and complimented with the "positive" idea of **capacities.**

Capacity refers to the conditions and characteristics that permit society at large (institutions, local groups, individuals, etc.) equitable access to and use of the social, economic, psychological, cultural and livelihood-related natural resources, as well as access to information and insitutions of governance necessary to reduce vunlnerability (adaptive or disaster risk reduction capacity) and deal with its consequences afterwards (coping and resilience). This definition approaches the definition of capabilities referred to in Amyrtya Sen's "capabilities approach to development" (Sen, 1983).

Some specialists see lack of capacity as being one dimensión of overall vulnerability, while others see it as a counter balance. The existence of vulnerability does not mean an absolute lack of capacities.

Introduced into disaster work by Anderson and Woodrow (1989) as a means, amongst other objectives, to shift the analytical balance from the negative aspects of vulnerability to the positive actions by people, the notion of capacity is fundamental to imagining and designing a conceptual shift favouring disaster risk reduction and climate change adaptation. Effective **capacity building,** the notion of stimulating and providing for growth in capacities**,** requires a clear image of the future with clearly established goals.

The notions of hazard, exposure, vulnerability, capacities and disaster risk as presented above reflect an emerging and increasingly consolidated understanding that disaster risk, while potentiated by an objective, physical condition, is fundamentally a "social construction", the result of social choice, social constraints, societal action and inaction. Risk assessment using both quantitative (actuarial and mathematical) and qualitative (e.g., social and psychological) measures are required to render a complete description (section 1.3; Douglas and Wildavsky, 1983; Wisner *et al.,* 2004; Cardona, 2004; Weber 2006). In considering the process of the social construction of risk, there is a long existing awareness of the role of development policy and practice in shaping disaster risk through, amongst other processes, the alteration of ecosystem structure and function, disregard for natural hazard events, a lack of land use planning, and an emphasis on emergency response to the detriment of risk reduction (UNEP, 1972; Hagman, 1984, Wijkman and Timberlake, 1988, Bender, 1989). Present day circumstances only reinforce that conclusion (Wisner *et al.,* 2004; UN, 2009). Where disaster risk reduction is successful, it is considered and practiced as a dimension of development planning (section 1.1.3, section 1.3.2, and chapters 5-8); risk can be effectively managed only through socially sustainable decisions and concerted human action (ICSU-LAC, 2010).

The contribution of physical events to disaster risk is characterized by statistical distributions in order to elucidate the options for risk reduction and adaptation (section 1.2 and chapter 3). But, the explicit recognition of the political, economic, social, cultural, physical and psychological elements of risk leads to a spectrum of potential outcomes of physical events, including those captured under the notion of **extreme social or ecosystem impacts** (section 1.2 and chapter 4). Where climate change introduces a break with past environmental systems functioning so that forecasting hazard becomes less determined by past trends, it is necessary to reconsider established indicators of human vulnerability. Sustainable and resilient disaster risk reduction under climate change will rely on direct management of risks, in the context of the wider socio-economic systems that can foster adaptive capacities while coping with experienced and expected disaster.

1.1.2.3. Response and Recovery from Disaster

Disaster occurs when a physical event triggers the actualization or materialization of disaster risk.

Disaster management, a component of comprehensive disaster risk management, begins once the immediacy of the disaster event has become evident and resources and capacities are put in place with which to respond ex ante and ex post. It includes early warning, contingency planning, emergency response (immediate post impact support for the satisfaction of critical human needs under conditions of severe stress) and, eventually, recovery. Disaster management is required due to the existence of "residual" disaster risk that neither ongoing disaster risk reduction or adaptation processes have managed to reduce sufficiently or eliminate (IDB, 2007). The response to disaster will affect future disaster risk reduction and adaptation efforts. The fostering of active grass roots community involvement, the use of installed local and community capacities, and the decentralization of decision making in disaster preparedness and response have been considered critical for improving future risk reduction and adaptation (Alexander, 2000; Wisner *et al.,* 2004).

Post-impact response and disaster recovery encompasses diverse concepts, of which **coping** and **resilience** are the most salient.

Coping (elaborated upon in section 1.4 and chapter 2) is defined here as the use of available skills, resources and opportunities to address, manage and overcome the adverse conditions associated with emergencies or disasters, with the aim of reaching some minimum accepted basic standard of normality in the short to medium terms. **Coping capacities** are the abilities of people, families, other groups, organizations, insitutions and systems, using available skills, resources and opportunities, to address, manage and overcome adverse conditions associated with emergencies or disasters. **Adaptive capacity** is defined as the ability of people, families, other groups and organizations, institutions and systems, using available skills, resources and opportunities, to positively anticípate and adjust to the risk associated with climate change and associated conditions (sea level rise, glacial ice loss, etc.).

The IPCC definition of adaptive capacity refers to "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" (IPCC, 2007b). This definition recognizes that adaptation can be anticipatory and planned (pro-active) and/or reactive and unplanned, and thus is very broad and inclusive, subsuming disaster risk management for climate-related risks as one type of activity through which society can deal with climate change impacts. The definition posits that adaptation is not only moderation of future damage but also coping with realized consequences (e.g. disaster), in contrast with the definition of adaptation as adjustment to or anticipation of risk (as opposed to disaster) used here (see section 1.4 and chapter 2).

Resilience is defined here as the ability of a system, society, organization or insitution, community, group, family or individual to anticipate, absorb, accommodate to or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation or restoration of its essential basic structures and functions. As Gaillard (2010) points out**,** this term has been used in disaster studies since the 1970s (Torry, 1979) and has its origins in engineering (Gordon, 1979), ecology (Holling, 1973) and child psychology (Werner *et al.,* 1971).

Although now widely employed in disaster risk reduction and adaptation work, resilience is subject to diverse interpretations. The term is used by some in reference to situations at any point along the risk or disaster "cycle" or "continuum", that is, before, during, or after the impact of the physical event. Others consider "vulnerability" and "lack of capacities" as sufficient for explaining the range of levels of success that are found in different recovery scenarios (Wisner *et al.,* 2004). Under this latter formulation, vulnerability both potentiates original loss and damage and also impedes recovery.

Finally, the term resilience, "bouncing back", and its conceptual cousin, coping, emphasize a return to a previous status quo or some other marginally acceptable level, such as "surviving", as opposed to generating a process that leads to improved conditions, as in "bouncing forward" or "thriving". The dynamic and often uncertain consequences of climate change (as well as development trends such as urbanization) for hazard and vulnerability profiles makes bouncing back an increasingly unattractive aim on risk management grounds. Increasingly, conceptions of resilience of social-ecological systems include the ability to self-organize, learn, and adapt over time. Chapter 8 draws out the importance of learning that is emphasized within this more forward-looking application of resilience. Chapters 2 and 8 address the notion of resilience and its importance in discussions on sustainability, disaster risk reduction and adaptation in greater detail.

1.1.3. Climate Change Adaptation and Disaster Risk Management

The reduction or prevention of climate-related disaster risk is a critical function of disaster risk management and climate change adaptation. However, the two practices do have significant differences as regards concepts, methodologies and practice that must be taken into account in the search for greater synergy between them.

Approaches to disaster and disaster risk management have undergone very significant changes over the last thirty years. These changes have occurred under the stimulus of changing concepts, multidisciplinary involvement, social and economic demands, as well as institutional changes reflected in the UN declaration of the International Decade for Natural Disaster Reduction in the 1990's, the establishment of the International Strategy for Disaster Reduction, and the 2005 Hyogo Framework for Action. Increasing emphasis has been placed on proactive disaster risk reduction as a dimension of development and development planning.

Developing and implementing means to respond to disasters has long been a primary objective of what has been known as "disaster" or "emergency" management. The recent emergence of disaster risk management reflects an increasing turn from disaster to disaster risk as the central concept and planning concern. Disaster risk management places greater emphasis on building resistance (the ability to not be damaged or seriously affected) to the potential impacts of physical events at various social or territorial scales.

Both climate change adaptation and disaster risk reduction comprise a corrective (that is, reactive) and prospective (that is, proactive) dimension, operating respectively under already existing and new expected or possible risk conditions (Lavell, 2003), covering the full spectrum of disaster risk contexts, from pre-impact conditions through to response and recovery.

Section 1.3 examines in more detail the process of transition to more development based disaster risk concerns and the current status of climate change adaptation practice as a prelude to examining the barriers and options for greater integration of the two practices.

1.1.4. Framing Disaster Risk Management and Adaptation Processes

At least two key fundamental contexts and questions arise in establishing the boundaries of the phenomena and social processes that concern disaster risk management and climate change adaptation and therefore highly influence their success: 1) the degree to which the focus is on extreme events, instead of on a more inclusive approach that considers the full continuum of physical events with potential for damage, the social contexts in which they occur, and the potential for such events to generate "extreme impacts" or disasters; and, 2) a consideration of the most appropriate socio-territorial scale (i.e., aggregations, see Schneider *et al.,* 2007) for fostering a deeper understanding of risk causation and risk intervention by involuntary or voluntary risk constructors, risk bearers, and the risk interveners.

1.1.4.1 Exceptionality, Extremity, Routine, and Everyday Life

Interpretations based on the physical causes and the role of extreme events in explaining loss and damage have been referred to as "physicalist" (Hewitt, 1983) while notions developed around the continuum of normal, everyday-life risk factors through to a linked consideration of physical and social extremes have been defined as "comprehensive", "integral" or "holistic" insofar as they embrace the social as well as physical aspects of disaster risk and take into consideration evolving experience, time, and history (Cardona, 2001; ICSU-LAC, 2010). The latter perspective has been a major contributing factor in the development of the so-called "vulnerability paradigm" as a basis for understanding disaster (Wisner *et al.,* 2004; Hewitt, 1983, 1997).

Additionally, attention to the role of small and medium scale disasters and their relationship to so-called "extensive risk" (UN, 2009) highlights the need to deal integrally with the problem of cumulative disaster loss and damage, looking across the different scales of experience both in human and physical worlds, in order to advance the efficacy of adaptation. The design of mechanisms and strategies based on the reduction and elimination of every day or chronic risk factors (Sen, 1983; World Bank 2001), as opposed to actions based solely on the "exceptional" or "extreme" events, is one obvious corollary of this approach. The ability to deal with risk, crisis, and change has been seen to be closely related to an individual's life experience with smaller scale, more regular physical and social occurrences (Maskrey, 1989; Lavell, 2003; Wisner, 2004). These concepts point toward the possibility of reducing vulnerability and increasing resilience to climate-related disaster by broadly focusuing on exposure and socially-determined susceptibility or sensitivity across a range of risks.

As illustrated in Box 1-1, many of the extreme impacts associated with climate change, and their attendant additional risks and opportunities, will inevitably need to be understood and responded to principally at the scale of the individual, the individual household, and the community, in the framework of localities and their organizational and management options, and in the context of the many other day to day changes experienced, including those of economic, political, technological, and cultural nature. As this real example illustrates, every-day life, history and a sequence of crises can affect attitudes and ways of approaching more extreme or complex problems. In contrast, many agents and institutions of disaster risk management and climate change adaptation activities necessarily operate from a different perspective, given the still highly centralized and top down approaches found in many parts of the world today.

_____ START BOX 1-1 HERE ____

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, in Tanzania. 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 plain, 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."

_____ END BOX 1-1 HERE ____

1.1.4.2. Territorial Scale, Disaster Risk, and Adaptation

Climate-related disaster risk, is most adequately depicted, measured and monitored at the local or micro level where the actual interaction of hazard and vulnerability are worked out in-situ (Lavell, 2003). At the same time, it is accepted that risk construction processes are not limited to specifically local or micro processes but, rather, to diverse environmental, economic social and ideological influences whose sources are to be found at scales from the international through to the national, sub-national and local, each potentially in constant flux (Wisner *et al.,* 2004). Changing commodity prices in international trading markets and their impacts on food security and the welfare of agricultural workers, decisions on location and cessation of agricultural production by international corporations, deforestation in the upper reaches of river basins and land use changes in urban hinterlands are but a few of such "extra-territorial" influences on local risk. Moreover, disasters once materialized have ripple effects that many times go well beyond the directly affected zones, as the early 2011 flooding in Queensland, Australia illustrated once more with regard to the overall impact on the national economy and other regions dependent on the affected areas for industrial inputs and services. Thus, disaster risk management and adaptation policy, strategies and institutions will very probably only be successful where understanding and intervention is based on multi-territorial and social scale principles and where phenomena and actions at local, sub-national, national and international scales are construed in interacting, concatenated ways (Lavell, 2002; UN, 2009; chapters 5-9).

1.1.5. A Summary: A Basis for Advancing Holistic, Integrated, and Interdisciplinary Understanding

We conclude that a more holistic, integrated, trans-disciplinary approach to risk assessment is needed to overcome and integrate the (at times) different approaches and visions provided by the climate change adaptation and disaster risk management communities and sub-communities (ICSU-LAC, 2010). Key aspects include the ways physical extremes and non-extremes are viewed, the manner in which vulnerability and changes and challenges in everyday life are depicted, and the way exceptional circumstances are characterized. Dividing the world up sectorally or thematically for management ends while offering undoubted advantages for certain levels of analysis, specialization and efficiency, may however undermine a thorough understanding of the complexity and interaction of the human and physical factors involved in the constitution and definition of a problem at different social, temporal and territorial scales. In contrast, an integrated approach would recognize the complex relationships between diverse social, temporal and spatial contexts and components and that participatory methods and basic decentralization principles could facilitate effectiveness of both climate change adaptation and disaster risk management.

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

1.2.1. Extreme Events, Extreme Impacts, and Disasters

Discussion and definition of (short duration) “extreme weather” or (longer lasting - months to years) “extreme climate” ‘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 or threshold-based definition of measured physical attributes of phenomena used by natural scientists and engineers (see chapter 3) to a concern with the fragility of social systems often expressed qualitatively by social scientists (chapter 2).

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 one may define extreme impacts, how climate change may affect our understanding of extreme events and extreme impacts, and how these topics might be considered and communicated.

1.2.2. Extreme Events Defined in Physical Terms

1.2.2.1. Definitions of Extremes

The full range of severe weather and climate reflects the interactions of dynamic and thermodynamic processes over a very wide range of space and timescales, resulting in highly variable atmospheric temperatures, motions, and precipitation, covering at least seven orders of magnitude of timescales - from the passage of an intense tornado lasting minutes to a drought lasting decades. Similarly, the spatial scale of severe weather varies from local to continental.

In addition to providing a long-term mean of weather, ‘climate’ characterizes the full spectrum of means and exceptionality associated with ‘unusual’ and unusually persistent weather. The World Meteorological Organization (WMO, 2010) differentiates the terms: “At the simplest level the weather is what is happening to the atmosphere at any given time. Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time.”

Where there is sufficient data to develop an overall distribution of a key weather or climate parameter, it is possible to define a value at some probability, as required in engineering design (this presupposes, however, that the climate over the period in which the parameter has been sampled is stationary (Milly *et al.,* 2008) and the record is long enough to capture low frequency events). The extremity of a weather or climate event of a given magnitude depends on geographic context (see section 1.1 and chapter 3): a month of daily temperatures corresponding to the expected Spring climatological daily maximum in Chennai would be termed a heat wave in France; a snow storm expected every year in New York would provoke a disaster when it occurs in southern China. Furthermore, the consequences of a one in ten annual probability event are, for some purposes, not sufficiently rare to result in unusual social consequences, which are specific to location and social context. Nonetheless, absolute, universal thresholds do also exist, e.g., a change in the incidence of freezing days may allow disease vectors to thrive. Also, an extreme event in the present climate may become much more common under future climate conditions. These various aspects are considered in the new definition of "extreme (weather and climate) events" provided in the glossary.

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The availability of observational data is of central relevance for defining climate characteristics and for disaster risk management, and while data for temperature and precipitation are widely available, some variables, such as soil moisture, are almost unmonitored, or, like extreme wind speeds and other low frequency occurrences, not monitored with sufficient spatial resolution or temporal continuity (chapter 3).

When the overall distribution of the mean climate changes, other parameters may shift relative to the change in the mean behaviour. For example a warmer mean climate could result from fewer cold days (leading to a reduction in the overall distribution of temperatures) or more hot days (leading to an expansion in the temperature distribution) or both. The issue of the scaling of changes in extreme events with respect to changes in mean temperatures is addressed further in chapter 3.

1.2.2.2. The Diversity and Range of Extremes

The identification and definition of all those weather and climate events that are relevant from a disaster risk management perspective depends on the stakeholders involved, and is broader than can be listed here. Out of the raw materials of precipitation, winds, and temperatures there is a broad concoction of severe 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 (McKee *et al.,* 1993) as well as excess evapotranspiration from the soil (Box 3.2) can be climate extremes. 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, as well as intense convective thunderstorms, presents a spectrum of size, forward speed, and intensity. In the extreme tail of the distribution of intensity there may be damaging extremes of surface winds, while slow forward speeds for intense storms lead to extremes of precipitation. A single extreme storm may bring extremes of precipitation and wind. The prolonged absence of winds is a climate extreme that can also be a hazard, leading to build-ups of urban pollution and disruptive fog (McBean, 2006).

1.2.2.3. Atmosphere-Hydrosphere Extremes

The behavior of the atmosphere is also highly interlinked with that of the hydrosphere and terrestrial environment so that extreme (or sometimes non-extreme) atmospheric events, such as for rainfall, may cause (or contribute to) other rare physical events such as extreme river levels, landslides and avalanches. Among the more important extreme events resulting from climate and weather interacting with the hydrosphere and geosphere are:

- Coastal flooding and severe wave action generated by large cyclonic storms reflecting wind and pressure related sea-level anomalies (Xie *et al.,* 2004).
- River flows (whether from intense precipitation, spring thaw of accumulated winter snowfall, precipitation falling on saturated ground, or an outburst from an ice, landslide, moraine or artificially dammed lake) exceeding the 1- or 2-year maximum, and thereby expanding beyond the natural channel (or for more extreme flows beyond the artificial defenses) to produce 'floods' (Gurnell and Petts, 1995). According to the scale of the catchment, river systems are tuned to react to particular durations of intense precipitation, with steep short mountain streams, and urban drainage systems responding to rainfall totals over a few hours, while peak flows on major continental rivers reflect precipitation extremes of weeks over extended areas (Wheater, 2002).
- Long term reductions in precipitation, or dwindling of residual summer snow and ice melt (Rees and Collins, 2006), or increased evapotranspiration from higher temperatures, often exacerbated by human

groundwater extraction, reducing ground water levels, causing spring-fed rivers to disappear (Konikow and Kendy, 2005).

- Landslides (Dhakal and Sidle, 2004) triggered by raised ground water levels after excess rainfall or melting slopes of permafrost.

Similarly, because physical impacts such as droughts, floods and landslides may occur as the result of a previously rare combination of several non-extreme events, changes in mean climate (e.g., mean temperature changes or mean precipitation changes) also need to be considered.

1.2.3. Extreme Impacts

1.2.3.1. Three Classes of Impacts

Some literature reserves the term "extreme event" for the initial meteorological phenomenon (Easterling *et al.,* 2000; Jentsch *et al.,* 2007), some includes the consequential physical impacts, like flooding, and some the entire spectrum of outcomes on humans, society, and ecosystems (Rich *et al.,* 2008). In this report, we use "extreme event" to refer to physical phenomena including some (e.g., flooding) which may have a human component to causation (chapter 3 and glossary). We contextualize "impact" to include: a) changes in the natural physical environment, like 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) loss or damage (according to a variety of metrics) to human or societal conditions and assets. An "extreme impact" reflects highly significant and enduring consequences to society or ecosystems. Disaster, as defined in this report (section 1.1), is comprised of extreme impacts on society, which may be associated with extreme impacts on the physical environment and on ecosystems. However, impacts are not always negative: flood-inducing rains can have beneficial effects on the following season's crops, while an intense freeze may reduce insect pests at the subsequent year's harvest.

Extreme impacts to human, ecological or physical systems can be the result of a single extreme event, a compound of extremes or non-extremes (for example, wildfire, followed by heavy rain leading to landslides and soil erosion), or simply the persistence of conditions, such as those that lead to drought (see chapter 9 for examples). Whether an extreme event results in extreme impacts to humans and social systems depends on the degree of exposure and the level of resistance, in addition to the magnitude of the physical event. Extreme impacts on human systems may be associated with non-extreme events where vulnerability and exposure are high (section 1.1, chapter 9). A key weather parameter may cross some critical vulnerability threshold at that location (such as heatwave-induced mortality, or frost damage to crops), so that the distribution of the impact shifts in a way that is disproportionate to physical changes. 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 impacts on physical (e.g., droughts, floods, sea level rise), ecological (e.g., forest fires) and human systems (e.g. casualties, infrastructure damages). For example, a large spatial scale of an extreme event can (as in an ice storm or windstorm) have an exaggerated disruptive impact due to the systemic societal dependence on electricity transmission and distribution networks (Peters *et al.,* 2006). Links between climate events and physical impacts are addressed in chapter 3, while links to ecosystems and human systems impacts are addressed in chapter 4.

1.2.3.2. The Extreme 'Event'

In considering the range of weather and climate extremes, along with their impacts, the term "event" as used in the literature does not adequately capture the compounding of outcomes from successive physical phenomena, e.g., a procession of serial storms tracking across the same region (as in Jan-Feb 1990 and Dec 1999 across Western Europe (Ulbrich *et al.,* 2001)). Sometimes locations affected by extremes within the 'same' large-scale stable atmospheric circulation can be far apart, as for example the Russian heatwave and Indus valley floods in Pakistan in Summer 2010 (Blackburn *et al.,* 2010). Atmospheric teleconnections also characterize the principal drivers of oceanic sea surface temperatures, and equatorial winds, in particular the El Niño Southern Oscillation.

The aftermath of one extreme may precondition successor events. High groundwater levels and river flows can persist for months, increasing the probability of a later storm causing flooding, as on the Rhine in 1995 (Fink *et al.,* 1996). A variety of feedbacks and other interactions connect extreme events and ecological responses in a way that may amplify physical impacts (chapter 3). For example, reductions in soil moisture intensify heat waves (Seneviratne *et al.,* 2006), while droughts following rainy seasons turn vegetation into fuel that can be consumed in wildfires (Westerling and Swetman, 2003, 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; for the next month, any cyclone whose path follows too closely will tend to lose intensity (Emanuel, 2001). Intense rainfall accompanying monsoons and hurricanes also brings great benefits to society and ecosystems; on many occasions they help to fill reservoirs, sustain temporal agriculture and alleviate summer drought conditions in arid zones (e.g., Cavazos *et al.,* 2008).

The attribution of extremes remains problematic and as a generality 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 (Hegerl *et al.,* 2007). A further complication is that extreme impacts 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 cause gradual sea level rise, compounding such future extremes (see Section 3.5.3 and 3.5.5).

1.2.3.3. Metrics to Quantify Social Impacts and the Management of Extremes

Metrics to quantify social and economic impacts (and thus used to define extreme impacts) may include, among others (Below *et al.,* 2009):

- Human casualties and injuries
- Number of permanently or temporarily displaced people
- Number of directly and indirectly affected persons
- Impacts to properties, measured in terms of numbers of buildings damaged or destroyed
- Impacts to infrastructure and lifelines
- Impacts on ecosystem services
- Impacts on crops and agricultural systems
- Impacts on disease vectors
- Impacts on financial or economic loss (including insurance loss)
- Impacts on coping capacity and need for external assistance.

All of these may be calibrated according to the magnitude, rate, duration, and degree of irreversibility of the effects (Schneider *et al.,* 2007). These metrics may be quantified and implemented in the context of probabilistic risk analysis in order to inform policies in a variety of contexts (see section 1.3.2.1).

Information on direct, indirect and collateral impacts is generally available for many large-scale disasters and is systematized and provided by organizations such as the Economic Commission for Latin America, large reinsurers, and the CRED database (CRED, 2010). Information on impacts of smaller, more recurrent events is far less accessible and more restricted in the number of robust variables it provides. The Desinventar database (Corporation OSSO, 2010), now available for over 24 countries worldwide, and the SHELDUS database, for the USA (HVRI, 2010), are attempts to satisfy this need. However, the lack of data on many impacts impedes complete knowledge of the global social and economic impacts of smaller scale disasters (UN, 2009, section 1.1)

1.2.3.4. Traditional Adjustment to Extremes

Disaster risk management and planned adaptation may be seen as attempts to duplicate or promote through planned mechanisms adjustments that society and nature have accomplished on many occasions “spontaneously” in the past.

A natural example of susceptibility (or resistance) is a tree uprooted or felled by or withstanding extreme winds. Resistance is strongly species-dependent, having evolved according to the climatology where that tree was indigenous (Canham *et al.,* 2001). In their original habitat, trees typically withstand wind extremes expected in their habitat every 10-50 years, but not extremes that lie beyond their average lifespan of 100-500 years (Ostertag *et al.,* 2005).

In contrast to natural systems, human systems (including systems of protection) have many times been explicitly designed to withstand a certain range of expected extremes. On the island of Guam, within the most active and intense zone of tropical cyclone activity on earth, buildings are constructed to the most stringent wind design code in the world, requiring a bunker style able to withstand wind speeds of $76ms^{-1}$ as expected every few decades (International Building Codes, 2003). The far greater frequency of mid-latitude extratropical cyclones than low latitude tropical cyclones means that for coastal habitation, indigenous building practices were less likely to be resilient in the tropics than in the windier (and storm surge affected) mid latitudes (Minor, 1983).

Communities accustomed to periodic droughts employ wells, boreholes, pumps, dams, and water harvesting and irrigation systems. Those with houses exposed to high seasonal temperatures employ thick walls and narrow streets, have developed passive cooling systems, adapted lifestyles or acquired 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 July 2003 (Vandentorren *et al.,* 2004) or California July 2006 (Gershunov *et al.,* 2009).

1.2.4. Distinguishing Disasters

Disasters may be viewed as extreme social impacts associated with severe disruptions of the routine functioning of the affected society. Extreme physical events or impacts do not on their own necessarily imply disasters. Some definitions of ‘disasters’ for the purposes of tabulating occurrences rely only on exceedance of thresholds of numbers of killed or injured, number of affected or repair costs (CRED, 2010; Below *et al.,* 2009). Building on the definition set out in Section 1.1.1, some have argued that societal impacts resulting from weather, climate or hydrological events become disasters once 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, although not necessarily totally eliminating) the capacity of the society to repair itself (Alexander, 1993). While extreme physical events may be the principal trigger of many very large or catastrophic disasters, a disaster may also arise from a concatenation of physical, ecological and social reactions to lesser physical events (Cardona *et al.,* 2009). Pre-existing social processes may exacerbate disasters and events, such as financial crises, trade policies, wars, disease outbreaks etc. 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’ due to the abrupt and circumstantial nature of the connotation commonly attributed to the word “event”, which belies the complexity and temporality of disaster.

1.3. Disaster Risk Management, Reduction, and Transfer

Risks appear in the context of human choices – such as where to live, in what dwellings, what vehicles to use for transport, what crops to grow, what infrastructure to support economic activities – that aim to satisfy human wants and needs (Renn, 2008). Ideally, any action to manage, reduce, or transfer disaster risk would involve consideration of the physical and biological systems that affect human wants and needs, and the ability to utilize these systems. Such actions would also take into consideration human judgments about what constitutes risk, how to weigh such risk alongside other values and needs, and the social and economic contexts that determine whose judgments influence individuals’ and societal responses to those risks. The concept of *risk governance* provides a useful framework for integrating consideration of these disparate but complimentary elements. Risk governance seen from the perspective of disaster risk management includes the core concepts of risk analysis and communication– as well as consideration of the legal, institutional and social contexts in which risks are perceived and assessed, and the networks of actors, rules, and institutions that help determine how judgments about risk are formed and acted upon (Renn, 2008).

1.3.1. Probabilistic Risk Analysis

Probabilistic Risk Analysis (PRA, see box 1-2) (Bedford and Cooke, 2001) provides an important set of quantitative 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 use this framework for the risk analysis stage of risk governance. In many contexts, other, qualitative approaches are preferable to PRA, while in some situations resources and capabilities to implement PRA are simply unavailable. Nonetheless, PRA provides widely applicable methods and an important conceptual foundation for much of disaster risk management and climate change adaptation.

_____ START BOX 1-2 HERE _____

Box 1-2. Probabilistic Risk Analysis

In its simplest form, PRA defines risk as the product of the probability that some event will occur and the adverse consequences of that event.

$$\text{Risk} = \text{Probability x Consequence} \quad (1)$$

For instance, the risk a community faces from flooding from a nearby river might be calculated as the likelihood that the river floods the town, inflicting causalities among inhabitants and disrupting the community's economic livelihood. This likelihood is multiplied by the value people place on those casualties and economic disruption. Eq (1) provides a quantitative representation of the qualitative definition of disaster risk given in Section 1.1. Alternative, more complex formulations express risk as a product of hazard, exposure, and vulnerability. All three factors contribute to "consequences". Hazard and vulnerability can both contribute to the "probability": the former the likelihood of the physical event (e.g. the river flooding the town) and the latter the likelihood of the consequence resulting from the event (e.g. casualties and economic disruption).

While simple in concept, Eq (1) is often difficult to implement in practice. As emphasized throughout this report, estimates of the likelihood of consequences arising from some physical event require judgments about a community's ability to resist damage and to recover from any damage inflicted (see discussion of vulnerability and resilience in Section 1.1). The valuation of consequences can be determine via a variety of metrics (see section 1.2.3.3) and may vary greatly from person to person, depending on factors such as their values and interests, their previous experience with such consequences, and the extent to which they feel they have any control over the consequences.

_____ END BOX 1-2 HERE _____

The PRA framework supports disaster risk management and climate change adaptation by providing information that can help in the evaluation and choice of options for managing, reducing, and transferring risk, and potentially, contribute to standardizing and integrating information and informing decisions across various levels of administration. Where one can quantify the costs of such actions in the same units as the consequences (box 1-2, Eq (1)), one can compare those costs to their resulting reductions of risk and evaluate which combinations of actions provide the greatest expected gains in welfare. For instance, insurance companies will estimate their expected losses by using simulation models to project the frequency and intensity of future events (hazards model) and the damage and its distribution caused by such events (vulnerability models). Firms combine this information with estimates of the fraction of damage property covered by insurance to help set their prices for such insurance (SwissRe, 2010). The framework, in conjunction with tools like spatial modeling, also supports administrative judgments of where risk does and does not exist, for instance flood risk maps which use estimates of threshold probabilities to categorize particular regions as at risk for floods. In this way, it can inform resource allocation decisions. Where quantification proves more difficult, the conceptual framework of PRA may nevertheless provide general guidance for decisions.

The overall risk governance framework put forward by Renn includes five steps: pre-assessment, appraisal, characterization/evaluation, management, and communications (Renn, 2008). PRA contributes most significantly to the characterization/evaluation stage.

1.3.2. Challenges in Implementing the Probabilistic Risk Framework

Many factors influence the outcomes of efforts to manage, reduce, and transfer risk, including some that create barriers to achieving outcomes perceived as satisfactory. Two factors – imprecise probabilities and difficulties in communicating about extremes -- present particular challenges to the characterization and evaluation of the risks associated with extreme events. A discussion of barriers in the more general context of maladaptation is found in section 1.4.3.2.

1.3.2.1. Challenge of Imprecise Estimate of Probabilities and Consequences

Extreme events, extreme impacts, and disasters pose a particular set of challenges for implementing probabilistic approaches because their relative infrequency often makes it difficult to obtain adequate data that could be used in Eq.1 to estimate the probabilities and consequences.

The likelihood of extreme events is most commonly described by the return period, the mean interval expected between one such event and its recurrence. 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 exceedance 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 (which translates into a 37% chance of a century passing without at least one such flood ($(1-0.01)^{100}=37\%$). The long return period of extreme events can make it difficult to reliably estimate their frequency. Statistical methods exist that can estimate frequencies longer than available data time series (Milly *et al.,* 2002). However, climate change presents the challenge of non-stationarity (Milly *et al.,* 2008), where the statistical properties of weather events do not stay constant over time. This exacerbates the already difficult estimation challenge by altering frequencies and consequences of extremes in difficult-to-predict ways (chapter 3; Meehl *et al.,* 2007; NRC, 2009; TRB, 2008).

Estimating the likelihood of various consequences and their value is at least as challenging as estimating the likelihood of extreme events. Projecting future vulnerability and response capacity involves predicting the behavior of complex human systems under potentially stressful and novel conditions. Section 1.4 describes some of the challenges such system complexity may pose for effective risk assessment. In addition, disasters affect socio-economic systems in multiple ways so that assigning a quantitative value to the consequences of a disaster proves difficult (see section 1.2.3.3). The literature distinguishes between direct losses, which are the immediate consequences of the disaster-related physical phenomenon, and indirect losses that are the consequences that result from the disruption of life and activity after the immediate impacts of the event (Pelling et. al., 2002; Lindell and Prater, 2003; Cochrane, 2004; Rose, 2004).

The disaster risk management and climate change 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 (Parson *et al.,* 2007). The fuzzy set approach is an efficient method for incorporating subjective uncertainty and addressing social issues, perception, and risk communication in management of disasters (Chongfu, 1996; Karimi and Hullermeier, 2007; El-Baroudy and Simonovic, 2004; Simonovic, 2011). To help communicate imprecision in probabilistic estimates, the IPCC uncertainty guidance (IPCC, 2006) asks for both quantitative judgments about ranges of probabilities and qualitative judgments about confidence in these estimates. Probabilistic 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. Barriers to Effective Communication about Extremes

1.3.2.2.1. Cognitive barriers

The literature on judgment and decision-making suggests various cognitive barriers to individuals and organizations properly assimilating and responding to information about low probability/high severity events. To be effective, disaster risk management and climate change adaptation would address these barriers by engaging a wide range of stakeholder groups -- such as scientists, policy makers, private firms, non-governmental organizations, media, educators, and the public -- in a process of exchanging, integrating and sharing knowledge and information. Sustainability science promotes interactive co-production of knowledge between experts and other actors, based on transdisciplinarity (Jasanoff, 2004; Pohl *et al.,* 2010) and social learning (Pelling *et al.,* 2008; Pahl-Wostl, 2009).

As described in the judgment and decision-making literature, the concepts of disaster, risk, and disaster risk management have very different meanings and interpretations in expert and non-expert contexts (Sjöberg, 1999a). Experts in the private and public sectors often apply the probabilistic risk analysis framework. In contrast, the general public, politicians, and the media tend to focus on the concrete adverse consequences of such events, absent from the probabilistic context (Sjöberg, 1999b). 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. By definition (if not always in practice), the application of understanding of risks associated with extreme events by experts is based in large part on analytic tools. Non-experts, on the other hand, rely to a greater extent on more readily available and more easily processed information. These gaps between expert and non-expert understanding of extreme events present important communication challenges (Weber and Stern, in press).

Quantitative methods exist that can allow people operating in expert contexts to use observed data, often from long time series, to make systematic and internally consistent estimates of the probability of future events. Individuals, including non-experts and experts making estimates without the use of formal methods (Barke *et al.,* 1997), often predict 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 past experience and thus will be relatively unavailable. Experts and non-experts alike may essentially ignore such events until they occur, as in the case of a hundred-year flood (Hertwig *et al.,* 2004). When extreme events do occur with severe and thus memorable consequences, people's estimates of their future risks will, at least temporarily, become inflated (Weber *et al.,* 2004).

Judgments of risk made in non-expert contexts may be 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 predictions about extreme events, making them "available", 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). Ignoring the risk of extremes is common in low income, hazard prone communities. Even with sufficient information, every day concerns and satisfaction of basic wants may supplant longer-term disaster risk concerns (Maskrey, 1988; Wisner *et al.,* 2004). Furthermore, some differences between expert and non-expert frameworks may reflect distinct cultural or philosophical approaches to risk rather than inadequate grasp of probabilistic approaches (Section 1.3.2.2.3).

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. Such asymmetry may arise from cognitive barriers as well as cultural and ideological influences (Section 1.3.2.2.3).

1.3.2.2.3. Influence of culture and ideology

In addition to being influenced by cognitive shortcuts (Kahneman and Tversky, 1979), the perceptions of risks and extremes by nonscientists and their reactions to such risks and events are also shaped by motivational processes (Weber, 2010). Cultural theory combines insights from anthropology and political science to provide a conceptual framework and body of empirical studies that seek to explain societal conflict over risk (Douglas, 1992). People's worldview and political ideology guide attention towards events that threaten their desired social order (Douglas and Wildavsky, 1982). Risk in this framework is defined not as damages or losses, but as the disruption of a social equilibrium. Personal beliefs also influence which sources of expert forecasts of extreme climate events will be trusted. Different cultural groups put their trust into different organizations, from national meteorological services to independent farm organizations to the IPCC; their values, beliefs, and corresponding mental models will be receptive to different types of interventions (Dunlap and McCright, 2008; Malka and Krosnick, 2009).

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). The US public's distrust of nuclear power following the accident at Three Mile Island provides an example of the cultural filtering of engineering safety data, where social amplification increased public perceptions of the risks of nuclear power far beyond levels that would be indicated by application of accident statistics in isolation (Fischhoff *et al.,* 1983). Such public transformation of expert-provided risk signals can be seen as a corrective mechanism by which cultural subgroups of society augment a science-based risk analysis with psychological risk dimensions not traditionally considered (Slovic, 2000). Evidence from health, social psychology, and risk communication literature suggests that social and cultural risk amplification processes modify perceptions of risk in either direction and in ways that may generally be socially adaptive, but can also bias reactions in socially undesirable ways in specific instances (APA, 2009).

1.3.3. Current Framework for Disaster Risk Management

Comprehensive approaches, such as those introduced in section 1.1 and box 1.2, are often more easily developed conceptually than practically, and are more accepted and utilized in academic, NGO and international agencies than in many national disaster or disaster risk agencies (Wisner *et al.,* 2004; Twigg, 2004; UN, 2009; Wisner *et al.,* forthcoming; Beer and Hamilton, 2002). Differential access to information and education, varying levels of debate and discussion, as well as contextual, ideological, institutional, and other related factors cause countries to exhibit a wide range of acceptance or resistance to the various challenges of risk management. One such challenge is to ensure the transition to greater emphasis on comprehensive Disaster Risk Management while not removing attention from disaster preparedness and response needs (see Hewitt, 1983; Smith, 1996; Tobin and Montz, 1997; Blaikie *et al.,* 1996; Hewitt, 1997; Wisner *et al.,* 2004, Lavell, 2003; Gaillard, 2010, for background and review of some of the historical changes in favor of disaster risk management). The introduction of disaster risk reduction concerns in established disaster response agencies may have led to a down grading of efforts to improve disaster response, distracting scarce resources in favor of risk reduction aspects (Alexander, 2000; Twigg, 2004; DFID, 2004; DFID, 2005).

The transition in favor of comprehensive or integral disaster risk management has been stimulated by the increasingly accepted and documented relationship between disaster risk and skewed development processes (Sen, 1982; Wijkmans and Timberlake, 1988; Hagmann, 1984; Lavell, 1999, 2003, 2009; Wisner *et al.,* 2004; UNDP, 2004; UN, 2009; Dulal *et al.,* 2009). For example, significant differentiation in the gains from development and in the incidence of chronic or every day risk, which particularly affect poorer persons and families, is widely accepted to be a major contributor to the more specific existence of disaster risk. A reduction of the rate of ecosystem services depletion, improvements in urban land use and territorial organization processes, the strengthening of rural livelihoods, and general and specific advances in urban and rural governance, are indispensable to achieving the composite agenda of poverty reduction, disaster risk reduction and climate change adaptation (UN, 2009).

The growing developmental and public sector economic impacts of disasters, particularly in small, poor and island state economies, has led to rapidly increasing concerns for post-impact financing of recovery. In this context the concept of risk transfer has received increased interest and salience. Also described as "risk sharing", this approach refers to mechanisms that permit risk to be transferred to willing third parties or be shared among a larger group, through financial vehicles such as insurance. 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 disaster risk reduction when insurance rates are allowed to reflect the existing level of risk, with rates being 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). Chapters 5, 6, 7, and 9 discuss risk transfer in some detail.

The gradual evolution of policies that favor disaster risk reduction objectives as a component of development planning procedures has inevitably placed the preexisting emergency or disaster response oriented institutional and organizational arrangements under scrutiny.

The prior absolute dominance of response-based organizations, where aspects of so-called disaster prevention were stimulated, has been complemented with the increasing incorporation of economic and social sector and territorial development agencies or organizations, as well as planning and finance ministries. Systemic, as opposed to single agency approaches, are now evolving in many places. Synergy, collaboration, coordination, and the development of multidisciplinary and multiagency schemes are increasingly seen to be required to guarantee risk reduction and risk management in a sustainable development framework (see Ramírez and Cardona, 1996, on the early 1989 creation and subsequent development of the then innovative Colombian system).

1.3.4. Climate Change Adaptation Framework

Climate change adaptation attempts to anticipate future impacts and respond to those already experienced. The early climate change literature focused on identifying and characterizing vulnerabilities to human and natural systems (IPCC, 1995). In recent years this literature has grown to include informing efforts to manage or reduce those vulnerabilities, as organizations worldwide have begun to take such actions (UNDP 2008; WDR 2010; ACC 2010). The current IPCC definition of adaptation envisions climate changes as the primary driver of adaptation decisions. While this view can inform trade-offs and synergies between adaptation and greenhouse gas mitigation, the climate change adaptation literature increasingly considers the concept of climate-related decisions, which are choices by individuals or organizations, the outcomes of which can be expected to be affected by climate change and its interactions with ecological, economic, and social systems (NRC 2009, Brown *et al.,* 2006, McGray *et al.,* 2007, Dulal *et al.,* 2009, Colls *et al.,* 2009). For instance, choosing to build in a low-lying area whose future flooding risk may increase due to climate change represents a climate-related decision. Such a decision is climate-related whether or not the decision makers recognize it as such.

A key concern and contribution of the climate change adaptation literature has been a focus on the need to anticipate future climate, biophysical, and socioeconomic conditions, which in general will be different to those in the present and affect the success of near-term decisions. Climate change adaptation aims to address changes on two different timescales: i) gradual, long-term changes in biophysical systems, such as sea levels, precipitation patterns, and the distribution of ecosystems and ii) weather extremes. Both types of changes can affect the level and complicate the management of disaster risk because many risks may become simultaneously more severe (chapter 3) and more difficult to estimate accurately. In some cases, the probability and consequences of both may have already changed outside the bounds of past historical experience (chapter 3 and 4).

Climate change adaptation has increasingly adopted an iterative risk management framework (Carter *et al.,* 2007; Jones and Preston 2011). This framework recognizes that the process of implementing PRA 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 (ACC 2010). A key challenge in implementing such iterative risk management for climate change adaptation is that 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 under-determined (NRC 2009; Morgan et. al., 2009). Such deep or severe uncertainty (Lempert and Collins 2007) 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 and other learning 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). Climate change adaptation approaches for addressing such uncertainties may contribute to disaster risk management (Schipper, 2009; McGray *et al.,* 2007; IIED 2009).

Both the climate change adaptation and vulnerability literatures often take an actor-oriented view (Nelson et. al., 2007; Wisner et. al., 2004; McLaughlin and Dietz 2007) that focuses on particular agents faced with a set of decisions and which can make choices based on their various preferences; their institutional interests, power, and capabilities; and the information they have available. The resilience literature shares an interest in the anticipation of and response to change but tends to take a systems view (Nelson et. al., 2007; Olsson et. al., 2006; Walker *et al.,* 2006; Berkes, 2007) that considers multi-interacting agents and their relationships in and with complex social, ecological, and geophysical systems (Miller et. al., 2010). The resilience literature can help disaster risk management and climate change adaptation to highlight issues such as the tension between resilience against specific, known disturbances and novel and unexpected ones, the tension between resilience at different spatial and temporal scales, and the tension between the ability of a system to persist in its current state and its ability to transform to a fundamentally new state (section 1.4; ICSU, 2002; Berkes, 2007).

Similarly to disaster risk management, the climate change adaptation literature increasingly emphasizes the importance of addressing climate change in the context of a broader range of issues. For instance, because in less developed regions vulnerability, adaptive capacity and exposure are critically influenced by existing structural deficits (low income and high inequality, lack of access to health and education, lack of security and political access, etc), scholars have argued that building adaptive capacity is a dialectic, two-tiered process in which climatic risk management (specific adaptation capacity) and deeper level socioeconomic and political reform (generic adaptation capacity) iterate to shape overall vulnerability (Lemos *et al.,* 2007; Tompkins *et al.,* 2008).

In-depth studies suggest that risk management alone will have limited success in reducing overall vulnerability despite increasing coping ability for those at risk. Particularly in the context of less developed regions, it is likely that the two forms of adaptation capacity are contingent on each other, that is, to access the benefits of climatic risk management, extremely vulnerable human systems require a minimum level of generic adaptation capacity. In Bangladesh, despite persisting poverty, improved disaster response and relative higher levels of households adaptive capacity has dramatically decreased the number of deaths as a result of flooding (del Ninno *et al.,* 2002; del Ninno *et al.,* 2003). However, in drought-ravaged NE Brazil, there are many examples of vulnerable households that lacked the minimum capacity to take advantage of risk management interventions such as seed distribution programs, either because they lacked money to travel to pick up the seeds or because they could not afford to forego a day's labor to enroll and participate in the program (Lemos, 2003). In Burkina Faso, farmers were limited in their ability to use seasonal forecasts (a risk management strategy) because they lacked minimal resources (basic agricultural technology such as plows, alternative crop varieties, fertilizers, etc.) to be able to respond to the projections (Ingram *et al.,* 2002).

Moreover, climatic risk management approaches can create positive synergies with development goals through participatory and transparent approaches (such as participatory vulnerability mapping or local disaster relief committees) that empower local households and institutions (e.g., (Degg and Chester, 2005; Nelson, 2005)).

1.3.5. Integrating Disaster Risk Management and Climate Change Adaptation

A principal goal of the present assessment report is to capitalize on the potential synergies between the fields of disaster risk management and climate change adaptation. Both fields share a common conceptual interest in understanding and reducing the risk created by the interactions of human and biophysical systems. Disaster risk management can help those practicing climate change adaptation to address impacts now and in the future. Climate change adaptation can help those practicing disaster risk management to more effectively address future conditions that differ from those of today. There are similarities in concepts, objectives and approaches that offer great promise for improved outcomes in both fields. In many countries, experience is growing on how to implement cooperative, inter-sector and multi or interdisciplinary approaches (ICSU, 2002; Brown *et al.,* 2006; McGray *et al.,* 2007; Lavell and Lavell, 2009; Lavell, 2010). Commonality revolves around a concern for the impacts of both extreme and non-extreme climate events on society under varying conditions of exposure and vulnerability; a concern for the reduction of vulnerability; and a concern with climate change and variability in the present-day and the future. Furthermore, concern for pre-impact risk management or adaptation is complimented with concerns for post impact response and recovery mechanisms in both fields.

The difficulties experienced with integration of these concepts and practices have been variously explained by differences in: historical and evolutionary processes; conceptual and definitional bases; processes of social knowledge construction and the ensuing scientific compartmentalization of subject areas; institutional and organizational funding and instrumental backgrounds; scientific origins and baseline literature; conceptions of the relevant causal relations and the relative importance of different risk factors, as well as the lack of full understanding between the fields in terms of content, significance and method (see Sperling and Szekely, 2005; Schipper and Pelling, 2006; Thomalla, 2007; Schipper and Burton, eds., 2009; Tear Fund, 2008, Mitchell and van Aalst, 2008; Lavell, 2010).

Three key distinctions in methods may also inhibit the integration process.

Firstly, disaster risk management concepts, theory and learning from practice has tended to encourage a bottom up, grass roots approach, increasingly emphasizing local and community based risk management in the framework of national management systems (see chapter 5 and 6). Disaster risk is location-specific and disaster risk management concerns and responses will often begin at the local or community level. On the other hand, climate change adaptation has to date tended to be driven from the top down, in part due to the difficulty of predicting future changes at the local level. Disaster risk management is also more likely to promote the use of territory as a point of reference, whereas climate change adaptation has tended to have an orientation toward social and economic sectors and macro ecosystems (as does much agency-driven disaster risk management practice).

Secondly, disaster risk management has placed an increasing emphasis on the social conditioning of risk and the construction of vulnerability as a causal factor in explaining loss and damage. Climate change adaptation has tended to place emphasis on physical events and exposure; seeing vulnerability as what remains after all other factors have been considered. However, community based adaptation work in developing countries has helped move this position further towards social causation aspects (Beer and Hamilton, 2002; Brown *et al.,* 2006; Lavell and Lavell, 2009; UNISDR, 2009b and c).

A route to overcoming the two foregoing differences in approach is indicated by the body of work on the determinants of adaptive capacity that focus on the interaction of individual and collective action and framing institutions (McCray *et al.,* 2007; Schipper, 2009)

Thirdly, climate change adaptation has tended to focus considerable attention on extreme events in its deliberations and discussions, and less on the concatenation of small and medium sized events or on multihazard contexts. The notion of adaptation to extreme physical events is considered impractical by some disaster risk management specialists (Lavell, 2009; Lavell, 2010). Such stakeholders tend to favor ideas on adaptation, adjustment, prevention or mitigation to changing climate means and to the much more regular, non-extreme, but still potentially highly damaging events. On going work for the 2011 Global Assessment Report from the UN has taken up on the theme of different risk strata and the question of what levels of risk are manageable by governments.

Differences have been emphasized regarding the overall coverage and concern of the two practices. Disaster risk management covers a wide range of hazard events (e.g. earthquakes and volcanoes), while climate change adaptation involves concerns for adjustments, amongst others, to changing climate means, sea level rise and loss of polar and glacier ice as well as ongoing concerns for health related aspects. Moreover, it has been suggested that disaster risk management is short term and passing in its outlook, whilst climate change adaptation is more long term and permanent.

However, such differences are not absolute (Birkmann and von Teichman, 2010; World Resources Institute, 2007; ECA, 2009; Lavell, 2010). Climate change adaptation, in addressing a full range of climate-related decisions, can often benefit from a disaster risk management multi-hazard framework; for instance, that relocation responses to sea level change are synonymous with contexts already dealt with historically by disaster risk management when addressing persistent flooding, landslides, volcanoes and such, and the demand for post disaster relocation; that loss of glacial ice melt supplies of water and resulting increased water deficit or drought problems are just further manifestations of water access problems suffered historically under other drought stressors; and that disease vectors and ensuing increased health problems in areas affected by adverse climate conditions have arisen under normal, observed conditions of the climate variability associated, for example, with the occurrence of El Niño.

As regards the time scale involved, it is clear that disaster risk management in its most recent conception and practice aims to anticipate risks associated with physical event return periods of hundreds, if not thousands of years and involves significant forward-looking decisions on prevention, investment and structural solutions. Moreover, climate change adaptation is not only long, but also short term, given its concern for climate changes that are already manifest and local and regional effects which need to be managed immediately in reactive or corrective fashion.

The following areas, some of which have been pursued by governments, civil society actors and communities, are among those that could be pursued in order to foster integration:

- Development of a common lexicon and deeper understanding of the concepts and terms used in each field (Schipper and Burton, 2008).
- Implementation of government policy making and strategy formulation that jointly considers the two topics (see The Central American Integral Disaster Risk Management Policy and Climate Change Strategies and the Philippines and Bangladesh country cases, for examples);
- Evolution of national and international organizations and institutions and their programs that merge and synchronize around the two themes, such as: environmental ministries coordinating with development and planning ministries (see the National Environmental Planning Authority in Jamaica and the Peruvian Ministries of Economy and Finance, Housing and Environment).
- Merging and/or coordinating Disaster Risk Management and Climate Change Adaptation financing mechanisms through development agencies and NGOs ;
- Using disaster risk management local level risk and context analysis methodologies with strong civil society participation and government buy in (Lavell and Lavell, 2009; UNISDR, 2009 b and c);
- Implementing bottom-up approaches whereby local communities integrate climate change adaptation, disaster risk management, and other environmental and development concerns in a single, causally dimensioned, intervention framework (Moench and Dixit, 2004; Lavell and Lavell, 2009).

1.4. Coping and Adapting

Coping and adapting are central concepts for disaster risk management and climate change adaptation in both scholarship and practice. Despite this fact the meanings of these terms are muddled. Even after focused efforts to parse these (Davies, 1993), they are often used interchangeably and great “conceptual confusion” remains (Davies, 1996). In general usage, coping focuses on employing immediately available resources to address present needs, while adaptation focuses on making resources available to address emerging needs and those that may increase in the future. The confusion in the disaster risk management and climate change literature derives less from doubts as to how to define these terms as such than from the lack of a clear consensus regarding the relationships between the two processes over time. As a result, there is no clear specification of how the adaptation process can be managed to maximal effect, reducing the need for societies to cope with extreme impacts associated with climate change. Such lack of clarity has the potential to complicate the efforts of governments to establish policies in this arena.

The present discussion thus has three goals. The first is to explore the relationships between coping and adapting. The second goal is to consider barriers to effective adaptation. And, the third is to reframe the notions of coping and adaptation in terms of learning from experience (see box 1-3), to highlight the role of learning in facilitating short term recovery and promoting appropriate longer term adjustments, and to facilitate the development of effective policy.

_____ START BOX 1-3 HERE _____

Box 1-3. Adaptation to Rising Levels of Risk

Properly implemented or achieved adaptation can shift a society's capacity to live productively with significant natural hazards. This is particularly the case when the historical distribution of hazard intensity is well known and relatively stable. In such instances, adaptation efforts over time can match a society's coping range with the hazards it typically encounters. As the following example illustrates, this process both depends on and facilitates further economic development, but adjustment in response to shifting hazard distributions is important to avoid increasing and maladaptive hazard exposure.

Before 1000 AD, 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, with a population of what is now the Netherlands estimated as 300,000 people, inhabitants had begun to construct the first dykes 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 stormy 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 lifespan; Gottschalk, 1971, 1975, 1977).

To adapt to increasing risk (reflecting long term delta subsidence), 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), 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 reflects increased protection rather than any reduction in storminess. Since 1953 the flood risk has been reduced at least an equivalent step further although this risk is considered now to be rising again due to climate change (Bouwer and Vellinga, 2007) and plans are being developed to manage further rises anticipated with increased inland and coastal flood hazard and again shift the coping range in anticipation of the new hazard distribution.

_____ END BOX 1-3 HERE _____

1.4.1. Definitions

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 thematic 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 or 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, relevant 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 with, are taxed (Wisner, *et al.,* 2004), whereas adapting suggests reorientation in response to past or anticipated change, often without specific reference to resource limitations.
- The second is constraint: in coping, survival is foremost and bounded by available knowledge, experience, and assets, and reinvention is a secondary concern (Bankoff, 2004), while in adapting, adjustment is the focus and limits are not the primary concern.
- The third is reactivity: coping is tactical and used to protect basic welfare and provide for basic human security or survival after an event has occurred (Adger, 2000), while adapting is strategic and focused on anticipating change and addressing this proactively (Fussel, 2007), even if spurred by recent events seen as harbingers of further change.
- 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 conditions and incorporates past tactics to the extent that they can facilitate adjustment, though according to some the two can overlap and blend (Chen, 1991).

Coping focuses on the moment, constraint, and survival; adapting focuses on the future where learning and reinvention are key, and short-term survival is less in question.

The definitions of coping and adapting used in this report reflect the connotations of the dictionary definitions. In particular, the glossary definition of coping emphasizes the use of available resources, skills, and opportunities to return to a basic standard of normality in the relatively near term after impact, while adaptation refers to adjustments, typically forward looking, in order to moderate future harm or exploit emerging opportunities. As an example, a community cannot adapt its way through the aftermath of a disastrous hurricane; it must cope instead. But adaptation in anticipation of the next hurricane can limit the coping that may be required. Importantly, in the aftermath, the use of certain coping mechanisms can limit the adaptation process, in ways that will be explored further below. It is also important to note that adaptation can (and often does) occur in the context of already changed climatic circumstances; the key is that those changed circumstances are expected to endure or, more commonly, to change further, necessitating a forward looking shift in disaster risk management. These relationships between the two concepts are not explicit in the definitions, but have been explored in the disaster and climate change adaptation literature.

1.4.2. Coping and Adapting in Current Usage

As noted above, the relationship between coping and adapting is unclear in both the disaster risk management and the climate change adaptation literature. This confusion extends to related terms such as coping capacity, coping range, and adaptive capacity. For instance, recent work on the topic has proposed various relationships between the two concepts, including synergy, in which coping is considered a means of advancing climate change adaptation (UNFCCC, 2003); recursive interactions, in which adaptation is seen to shift the coping range, or range of climate-related hazards that a society can successfully engage without incurring substantial losses (Smit and Pilifosova, 2001; Yohe and Tol, 2002; Jones and Mearns, 2004); temporal dependence, based on the assertion that coping occurs in the present and adaptation is a process that is realized over time (Brooks, 2003); and conditionality, as short term coping efforts are seen to erode the capital required for longer term adaptation (Adger, 1996). The imprecision that derives from these varying relationships is compounded when other terms whose meanings are contingent on a particular disciplinary connotation, such as resilience, are introduced.

Coping was first used in disaster work to refer primarily to survival strategies when practice was focused on reactive, response-based disaster or emergency management. As the disaster management community began to reorient its thinking toward disaster risk management in a development framework, in the 1980s, it embraced coping as a means to engage local populations and utilize indigenous knowledge in disaster preparedness and response (Twigg, 2004). Coping mechanisms were sometimes grouped with adjustment mechanisms useful for advancing development objectives (Clarke Guarnizo, 1992). There was concern, however, that this would divert attention away from addressing structural problems that could obviate the need for coping in the future (Davies, 1993), a focus on “surviving” instead of “thriving”. Since then, there has been persistent discussion over where coping fits in the disaster risk management cycle and whether it is primarily *ex-post* or both *ex-ante* and *ex-post* disastrous events (UNISDR, 2008b; UNISDR, 2008c; UN, 2009) while the term has been used to refer both to strategies used to avoid risk (Ribot, 1996) and to strategies used to endure it, with an overall shift toward a focus on surviving a disastrous event. Thus, the current UNISDR definition of coping capacity is the ‘ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters’ (UNISDR, 2009d).

The climate change adaptation literature is primarily focused on the process of adaptation rather than on coping with discrete events. In this literature, coping is sometimes used as a standalone term in its conventional sense, i.e. as a means of surviving a shock, but equally often as part of the phrases coping capacity or coping range, synonyms that refer to the boundaries of a system’s ability to survive and recover from a shock (Yoho and Tol, 2002). Coping range has been defined in part as a function of a system’s prior adaptation (both autonomous and planned) (Hewitt and Burton, 1971; De Vries, 1985; De Freitas, 1989). The relationships between the use of coping strategies in response to a stress event, the recovery process, and the implications for long term development have received less attention in the climate change adaptation literature. The climate change literature does note the potential for coping strategies to deplete capital, with potential implications for future adaptation activities (Adger, 1996; Risbey *et al.,* 1999), and several other similar concerns have been discussed in regards to maladaptation (Barnett and O'Neill 2009). In contrast, however, some have suggested that coping mechanisms can be an initial if insufficient step in the adaptation process (Frankenberger and Goldstein, 1990). Summing the range of possibilities, Schipper and others (2011) note “while the ability to cope may suggest some resilience, the coping actions themselves may lead either to increased resilience, exposure and/or sensitivity over time”. Overall, coping is acclaimed as tactical and noted to be a potential bridge to adaptation, in the sense that a community must survive in order to adapt. The resources put into building this bridge, however, would be more strategically deployed if used to enhance system adjustments.

1.4.3. Barriers to Successful Adaptation

Regardless of the terms used, there are interactions between coping and adaptation at several levels. While coping mechanisms facilitate survival, they also entail costs, and have the potential to shift a community into what has been termed transient poverty (Lipton and Ravallion, 1995). Rather than leaving resources for adaptation, communities forced to cope can become increasingly vulnerable to future risks (O'Brien and Leichenko, 2000). Successful adjustments can widen and shift a community’s coping range, enabling it to absorb a wider range of future disaster risks (chapter 9). Thus there is a recursive relationship between past exposures, current coping range, adaptive capacity, and future risk. How this relationship is mediated and the impediments to successful adaptation are the focus of this sub-section.

1.4.3.1. Adaptation Failures and Maladaptation

While adaptation, particularly planned adaptation, has the potential to expand and shift the coping range into better alignment with anticipated new risks, not all adaptation efforts will be successful. Indeed it is difficult to arrive at one universally accepted approach to identifying a successful adaptation measure, as the impact of particular adaptation activities on disaster risk depends on the lens through which adaptation is viewed (Adger *et al.,* 2005). Deferring the process of defining successful adaptation, however, it is still possible to discuss adaptation failures, which fall into two broad categories: adaptation efforts that are derailed as a result of barriers that interrupt, delay, or stop the adaptation process; and adaptation efforts that achieve the stated objective but nevertheless increase overall risk. The two categories have similar causes, an issue to which we will return after briefly discussing these in more depth.

A host of barriers can undermine planned adaptation efforts. Moser and Ekstrom (2010) outline an adaptation process that includes understanding, planning and management (each containing several essential steps) and note that there are barriers at each step that can cause the adaptation process to fail. For instance, they note that adaptation efforts can fail before they begin as a result of barriers to understanding, including difficulty recognizing a changing signal due to difficulty with its detection, perception, and appreciation; preoccupation with other pressing concerns that divert attention from the growing signal; and lack of administrative and social support for making adaptive decisions. Other barriers can arise in the planning and management stages of the adaptation process in similar fashion, resulting from complex interactions between a wide range of actors, their perceptions, and the systems they manage, all over time. Planning barriers, for instance, can result from failure to adequately identify the full range of possible management options or from perceptions related to the feasibility of these, while management barriers may result from insufficient control over identified options, and lack of authorization, or insufficient material support to implement and monitor the chosen options.

In the climate change literature, maladaptation has been defined as “action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups” (Barnett and O'Neill, 2009). Barnett and O’Neill identified five types: adaptation activities that increase greenhouse gas releases; adaptation activities that burden vulnerable populations disproportionately; adaptation activities with relatively high opportunity costs; adaptation decisions and actions that reduce incentives for further adaptive action; and adaptation decisions that require excessive commitment to one path of action. Another type includes actions that offset one set of risks but increase others (perhaps unrelated to climate change), resulting in net risk increase, such as a dam that reduces flooding risk but increases the risk of certain vector-borne and zoonotic diseases and has an overall net negative impact on morbidity and mortality even after flood-related illness and death are taken into account.

Management 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 and the issue frequently arises in managing large insurance systems. One common mechanism is the implementation of a risk management device that has the potential to provide false comfort if risks are not continuously reassessed, if risk management strategies and devices are inadequately maintained, or if other risk management strategies are not recruited as necessary. This was the case with the levees in New Orleans prior to Hurricane Katrina, termed the “safe development paradox,” wherein the levees were built to make a hazardous area safe but paradoxically a much larger population was exposed to catastrophic risk. As a result of multiple factors that have been termed the “local government paradox,” (Burby, 2006) crumbling levee infrastructure increased the risk of flooding but no other adequate risk reduction and management measures were implemented, resulting in catastrophic loss of life and property when the city was hit with the surge from a strong category 3 storm (Comfort, 2006).

Some have suggested that, as a result of the federal government’s historical approach to natural disasters, those whose property was at risk in New Orleans anticipated that they would receive federal recovery funds in the event of a flooding disaster, and that this distorted the risk management landscape, resulting in improper pricing of flooding risks, decreased incentives to take proper risk management actions, and thus exposure of a larger population to flood risk than otherwise might have been the case (Kunreuther, 2006). This instance illustrates the impact of maladaptive risk sharing and demonstrates the importance of considering 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).

This issue brings into relief the potential for large insurance systems to subsidize risk, moral hazard (see Section 1.3.3), and the issue of maladaptive risk management practices mediated through both public and private insurance programs. 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). In such a case, barriers to adaptation (in both planning and management, in this case) result in a strategy with maladaptive consequences. In places where risk levels are rising, climate change may prompt reconsideration of these barriers to promote more adaptive risk management.

Ultimately, maladaptive processes run the risk of committing collective resources (public or private) to coping and recovery rather than adaptation; they sometimes also run the risk of forcing some segments of society to cope with higher levels of risk than they otherwise might. Ensuring an approximate match between a wide range of possible risks and their appropriate risk management strategies is complex, however, and faces its own set of issues, the focus of the next section.

1.4.3.2. The Role of Complexity

There are many sources of both maladaptation and the other barriers to effective adaptation. Many, at base, are the result of 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. There is often also a component of significant resource constraints and competition between multiple urgent priorities as well as insufficient linkage between costs and benefits across sectors and communities. In many settings, one major source of maladaptation results from incomplete awareness, appreciation, and acceptance of system complexity in the risk management process. In particular, 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) (these categories roughly parallel Moser and Ekstrom's (2010) framework regarding adaptation barriers.)

Each of these problems results in a different type of maladaptation. Complexity that hinders evidence generation (see section 1.3.2) limits knowledge of risk. In such instances, some risks are increased by incomplete understanding of the hazard universe (or the universe of relevant risk management strategies). This problem can be compounded by the issues of high specialization, narrow disciplinary focus, and short-term perspectives, each of which can undermine proper calibration of risk management decisions.

Complexity that limits learning from evidence is often the result of heuristics or mental models (Kahneman *et al.,* 1982) that lead to "systematically erroneous but strongly self-confirming inferences" (Sterman 2006; also see Section 1.3.2), complicate policy action among both experts and lay people (Cronin *et al.,* 2009). Complexity can lead to misunderstanding, for instance of the impact of flows in and out of a stock over time (e.g., the relationship between annual deficits and national debt). In regards to climate change, such errant mental models lend disproportionate reliance on a "wait and see" approach to mitigation (Sterman, 2008). This dynamic is also associated with the difficulty of weighing different levels of risk, (see section 1.3.2) some of which are more immediate but less devastating, 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 as well as complexity in confronting and managing the tradeoffs between different priorities and their impacts across sectors, populations, and generations. These issues can lead to paralysis and failure to engage in appropriate risk management strategies despite the availability of compelling evidence suggesting an appropriate risk management path. An example of this is the resistance to immunization policy recommendations among some subsets of the population, particularly regarding measles-mumps-rubella vaccination, which has been repeatedly correlated with disease outbreaks in communities with lower vaccination rates (Jansen *et al.,* 2003). Here again mental models and heuristics affecting risk perception come into play, complicating an evidence-based approach to risk management policy making as discussed in Section 1.3.2 and necessitating strategies for anticipating and addressing these barriers to adaptation policy formation.

Each source of maladaptation or policy resistance – complications with evidence generation, evidence interpretation, and evidence application – is relevant to the present discussion. The complexity of the climate system impeded accumulation of compelling evidence that the climate was changing until the second half of the twentieth century, and there remains significant lay skepticism despite widespread scientific consensus. Complexity also dogs the generation of estimates regarding how the frequency and severity of extreme events may shift with climate change as well as the process of deploying probabilistic risk management strategies using these estimates to promote appropriate adaptation efforts (section 1.3.2). Finally, conflicting perceptions and messages related to climate change impacts and distrust of expert opinion and consensus findings (Schrope, 2001) complicate development and action on a unified climate change risk management platform (see Section 1.3.2.2).

1.4.3.3. Adaptation with No Regrets

Disaster risk management decisions often pivot on thresholds: strategies that were conceived under one set of threshold assumptions can become maladaptive under another (Niemeyer *et al.,* 2005). For example, levees protecting established communities in flood prone areas might be adaptive for anticipated floods of a certain magnitude, but maladaptive when the maximum projected flood height for a given period shifts, unless new adaptation measures are taken, e.g. raising the levees. In such an instance, the (unchanged) 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 feel safe but in fact are not (the "safe development paradox" noted above). 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).

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 (elaborated below) 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)

To address the challenge of risk management in the dynamically complex context of climate change and development, as well as under conditions where probabilistic estimates of future climatic conditions remain imprecise, the climate change adaptation literature has employed the concept of robustness. Robustness is a property of a plan or strategy that performs well over a wide range of plausible future scenarios even if it does not perform optimally in any particular scenario. Robust adaptation plans may avoid brittleness even if probabilistic assessments of risk prove wrong because they aim to address both expected and surprising changes, and may allow diverse stakeholders to agree on actions even if they disagree about values and expectations (Means et. al., 2010; WDR 2010; Brown and Lall, 2006, Dessai and Hulme; 2007; Lempert and Groves, 2010). Robust plans thus include 'no regrets' as a special case. To maintain their robustness over time, learning must be a central pillar of adaptation efforts.

1.4.4. Learning, Coping, and Climate Change Adaptation

The climate change adaptation literature emphasizes the importance of learning and plans that are explicitly designed to evolve over time in response to new information (Morgan et. al. 2009: NRC 2009). Learning has also been a long-standing focus in the resilience literature. For instance, adaptive management, an important framework in environmental management, rests on the notion that policy interventions should be viewed as experiments and learning opportunities for gathering additional information about the behavior of complex systems, including their response to management. 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 (Gunderson *et al.,* 2010). Recent literature has also seen an emphasis on what is called adaptive governance (Olsson et. al., 2006; Scholtz and Stiffel 2005). This approach extends adaptive learning to the design and modification of institutions.

Of particular relevance is the distinction between different types of learning, including single-loop and double-loop learning processes (see Figure 1-2).

[INSERT FIGURE 1-2 HERE
Figure 1-2: Learning Loops: Pathways, outcomes, and dynamics of single, double, and triple loop learning (adapted from Sterman *et al.,* 2006; Folke *et al.,* 2009; and Argyris and Schön, 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. Single loop learning is often analogous to coping in response to hazard exposure: it can reduce risk if invoked quickly enough, or minimize and contain damage in the aftermath of a hazardous event. Double-loop learning, in contrast, is more analogous to adaptation. 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. Such double loop learning may also include shifts in people's attitudes and practices in response to information about crash frequency and distribution. 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 (see section 1.3.2.2.3) are changed in response to evidence that these deep social structures are not serving a larger agreed upon goal, i.e. are maladaptive when assessed in a more comprehensive risk-benefit calculus. Extending the driving example further, triple-loop learning might 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 forms of active transport. Such a shift would reduce not only the risk of injuries from motor vehicle crashes, but also the risks associated with obesity including cardiovascular disease and diabetes, reducing health care costs in the bargain, as demonstrated by several various analyses (Bell *et al.,* 2008; Younger *et al.,* 2008; Haines *et al.,* 2009; Rissel, 2009; Woodcock *et al.,* 2009).

For such triple loop learning to be translated into policy, however, requires not only articulation of a larger risk-benefit universe, but also mechanisms to identify, account for, and compare the costs associated with a wide range of interventions and their benefits and harms over various time horizons. Stakeholders must also collaborate to an unusual degree in order to collectively and cooperatively consider the wide range of risk management possibilities and their impacts. If single-loop learning is analogous to coping and double-loop learning to adaptation, then triple-loop learning may be analogous to what some have termed transformation (Kysar, 2004): triple-loop learning may lead to recasting social structures, institutions, and constructions that contain and mediate risk 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. Learning of all types is clearly pivotal to this process. Coping is occasionally necessary for survival but is a last resort. Prioritizing learning as part of the risk management process may facilitate careful consideration of the hazard landscape and the ways in which it is changing, reducing the need for coping strategies.

1.4.4.1. Learning from Disaster Risk Management Relevant to Overcoming the Barriers to Climate Change Adaptation

(To be completed for FGD)

1.5. Structure of this Report

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 addressed 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 historical and expected changes in the frequency and intensity of heat waves, tropical storms, El Nino, monsoons, etc. The SREX builds on AR4 and updates the earlier assessments, which in some instances, due to new literature, leads to revisions. 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 events 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 assess disaster risk management and climate change adaptation from the perspectives of local, national, and international governance institutions and approaches, respectively, taking into consideration the roles of individuals, NGOs, the private sector, and other civil society institutions and arrangements.

Chapter 5 focuses 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, knowledge generation and sharing, legal frameworks, and practices that characterize international agencies and cooperative arrangements. This chapter also discusses integration of responsibilities across all governmental scales, emphasizing the linkage between DRM, CCA, and development.

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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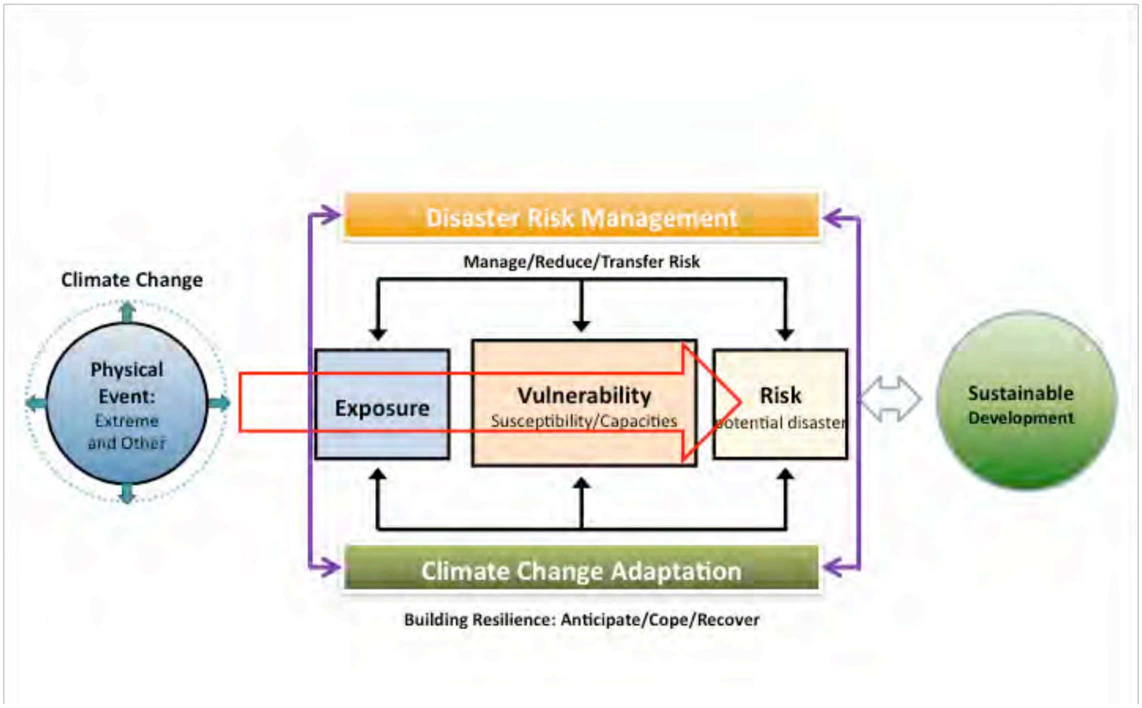

Figure 1-1: The key concepts and scope of this report. The figure indicates schematically key conceps involved in disaster risk management and climate change adaptation, and the interaction of these with sustainable development.

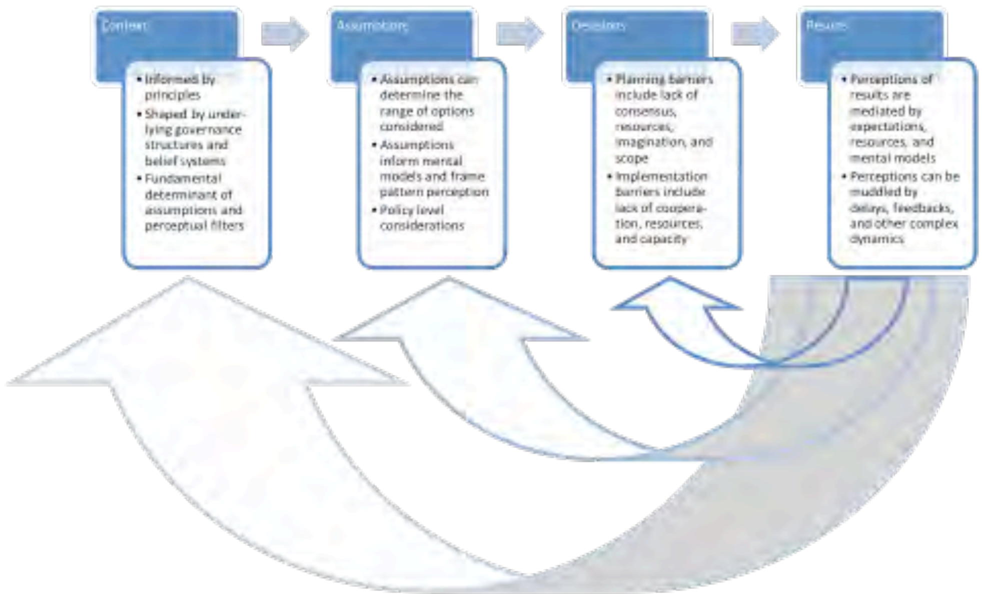

Figure 1-2: Learning Loops: Pathways, outcomes, and dynamics of single, double, and triple loop learning (adapted from Sterman *et al.,* 2006; Folke *et al.,* 2009; and Argyris & Schön, 1978).

Chapter 2. Determinants of Risk: Exposure and Vulnerability

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Contents

Executive Summary

Vulnerability and exposure are key determinants of disaster risk. A better understanding of risk, not only focusing on hazards but particularly also including vulnerability and exposure, is essential for the adaptation policy and practice [2.1, 2.2, 2.7, 2.8].

Adaptation and disaster risk management are rooted in the same understanding of vulnerability. Although different communities of practice and thinking on disaster risk management and adaptation to climate change label the concepts differently and emphasize different entry points for interventions, there is an agreement that causal factors of vulnerability fall into two broad categories: one focused on susceptibility/fragility to hazards and the other on lack of capacity/resilience [2.2, 2.3, 2.4].

Disaster risk is the result of the interactions of probable physical events with exposed vulnerable elements of social systems. Hazards arise when physical and biological processes interact with social processes. Manifestations of this interaction are disasters when losses of life and/or livelihoods transpire and damage to infrastructure occurs. [2.2, 2.3]

Disaster risk may be associated with differing levels of potential loss and damage, defined differently dependent on the context, e.g. the spatial scale of assessment**. Some events have limited human impact but very large financial costs or vice versa.** [2.2]

The accumulation of the effects of many small disasters may be as damaging or worse than one large disaster. Small events, often only registered at sub-national and local levels, can have chronic impacts on sustainable development, especially for the most fragile socio-economic groups. [2.9]

Vulnerability and exposure are highly context specific and dynamic, because they are driven by physical, environmental, economic, social, cultural, institutional and governance dimensions, which themselves are non-stationary. [2.2, 2.5, 2.7]

People are differently vulnerable and exposed according to characteristics such as wealth, gender, age, race/ethnicity/religion, disability and health status, and class/caste. Risk management policy and practice has often been ineffective in addressing this differential nature [2.5].

Lack of resilience and capacity to anticipate, cope with and adapt to shocks and change are important causal factors of vulnerability [2.4].

Vulnerability and exposure can be affected both positively and negatively by approaches taken to managing 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 and sustainable development. [2.2, 2.4]

There is high confidence that changes in exposure and vulnerability are the main drivers behind observed trends in disaster losses, and will be continue to be essential drivers of changes in risk patterns over the coming decades [2.1, 2.7].

Key drivers of these changes include population growth, changing demographics and health status, changing settlement patterns including urbanization, economic growth, environmental degradation, science and technology, gradual shifts in climate and its variability, as well as institutional and governance issues. Important complexities arise from feedbacks among these drivers, the accumulation and social amplification of risk, dynamic changes in vulnerabilities, and different phases of crises and disaster situations. [2.7, 2.9]

There is high confidence that climate change will affect disaster risk not only through changes in the frequency, intensity and duration of some extreme events (see chapter 3), but also through indirect effects on vulnerability and exposure, for instance through impacts on the number of people in poverty or suffering from food and water insecurity, changing disease patterns and general health levels and where people live. In some cases, these changes may be positive, but in many cases, they will be negative, especially for many groups and areas that are already among the most vulnerable. [2.7]

Comprehensive risk assessment is important for reducing vulnerability. However, there are methodological and data gaps in risk assessment that need to be filled to inform appropriate interventions (risk reduction/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, indices or probabilistic risk modelling are important tools for risk analysis and vulnerability assessment. However, no indicator or model fits all purposes, and improvements are needed to better capture dynamic aspects of vulnerability and risk, including societal response. [2.6, 2.8]

Effective disaster risk management and adaptation depends on appropriate risk communication. Impediments to information flow (bottom-up and top-down) are risk amplifiers. Effective communication of risks requires new formats of communication that deal appropriately with uncertainty and complexity. These uncertainties not only include the climate information, but particularly also current and future exposure and vulnerability. Bottom-up participatory assessment methods can help overcome some of these challenges. [2.8, 2.9]

Key research gaps include the lack of good information on vulnerability and exposure (at various scales), but also its proper use to inform robust decisions where uncertainties are high. Other areas that merit further attention include decision analysis and stakeholder engagement, characterization and quantification of indirect feedbacks between climate change and disaster risk, and assessment of systemic risks. [2.10]

2.1. Introduction and Scope

Many climate change adaptation efforts aim to address the implications of potential changes in the frequency, intensity and duration of "extreme events", with "extreme" usually defined by the nature of the impacts rather than the meteorological events themselves. To properly assess the implications of potential changes in such events, 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, there is high confidence that at least for those hazards where such analysis is available, changes in exposure and in some cases vulnerability have generally created larger and faster changes in risk than trends in climate and weather extremes due to anthropogenic climate change (e.g. Bouwer *et. al*., 2007; Pielke and Landsea, 1998; UNISDR 2009), although this comparative importance may change as climate change progresses, particularly if it reaches the upper ends of current projections for this century. However, even then, vulnerability and exposure will continue to be key determinants of aggregate risk. 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 changes in those dimensions. This chapter aims to provide that underpinning of the SREX, by further exploring the determinants of risk as presented in chapter 1, and thus demonstrating the fundamental entry points for disaster 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. 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). 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 risk management challenges 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.

Beyond analytical characterization of determinants risk, this chapter also highlights the essential role of risk perception and communication, and the importance of integration of bottom up and top down information, overcoming impediments to the flow of information across scales, and finally clarifying and communicating the risks of living in a particular location. Behind the 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.

The first sections of this chapter elucidate the concepts that help to define and understand 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 (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 more quantitative perspective on trends is provided in chapter 4). 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

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 that has not yet materialized. The social materialization of risk can be understood by thinking about risk in terms "a becoming-real" of a social construction (Beck, 2000, 2008; Adam and Van Loon, 2000). Risk can thus be defined as the possibility that an undesirable state of reality (adverse effects) will occur as a result of natural or socio-natural events (Luhmann, 1990). Hence, risk can be something measurable in probabilistic terms, what is useful for resource allocation. However, interventions can also be based on social values and preferences (Renn, 1992).

The conceptual frameworks used to understand and interpret risk as well as vulnerability and the associated terminologies have not only varied over time, but also differ according to the disciplinary perspective considered (see e.g. Cardona 2004, Birkmann 2006, Turner et al. 2003, Füssel and Klein 2006). Although researchers and professionals working on disaster risk and climate change adaptation 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 from the perspective of equity, legitimacy, sustainability, flexibility, etc. (Cardona, 2004).

Disaster risk refers to the probability of future damage and loss associated with the occurrence of hazard events (as defined in chapter 1). Risk may be associated with differing levels of potential loss and damage and may at times reach the level of a catastrophe or at others the level of a small disaster (defined differently dependent on the spatial scale); some have limited human impact but very large financial costs or vice versa (Alexander, 1993, 2000; Quarantelli, 1998; Birkmann 2006b; Marulanda *et al.,* 2008b, 2009, 2010; United Nations, 2009).

It is important to remark that the hazard event is not the sole driver of risk. The levels and types of loss are also determined by the exposure and vulnerability of society (UNDRO, 1980; Cardona, 1986, 1993; UNISDRa, 2004, 2009b; Birkmann, 2006a/b). Disaster risk is the result of the interactions in time and space of probable physical events with exposed vulnerable elements of social systems (Cuny, 1984; Davis and Wall, 1992). Through such interactions, physical events are transformed into hazards with the potential to generate future loss and damage. Disaster risk may be seen as a continuum in constant evolution and disaster one of its many "moments" or "materializations" (ICSU-LAC, 2010). Then, disasters reflect and signify unmanaged risks and may also be seen as representing unresolved development problems (Westgate *et al*., 1976; Wijkman and Timberlake, 1984).

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). Understanding disaster risk management as a social process that searches to forecast, control and reduce disaster risk drivers –such as hazard, exposure and vulnerability– in a development framework, by means of the design and implementation of appropriate policies, strategies, instruments and mechanisms (Cardona and Barbat, 2000), effective disaster risk reduction and adaptation require shift from focus on the disaster event towards understanding of disaster risk (Cardona *et al.,* 2003a). This understanding minimally requires knowledge about (ICSU-LAC, 2010):

- *Hazard*, 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.

Hazard was defined in chapter 1 and, in general, it refers 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). 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). 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 climate change are the most notable examples of socio-natural hazard phenomena (Lavell 1996, 1999a). Anthropogenic hazards include contamination of air, land and water; urban and rural fires; spills of toxic substances; rupture of dams and dykes etc. There are also biological hazards and cases of conjoint and concatenated hazards such as the NaTech events. The study of hazards typically involves the natural, earth- and applied sciences. Each hazard is characterised by its location, intensity, speed, onset and frequency.

At present the effects of climate change on frequencies and intensities of hazard events are key fields of research (ICSU-LAC, 2010). In this context hazards are related to the probability of extreme weather phenomena –such as intense tropical storms–, or of the physical impacts of climate extremes on the natural environment, especially through the local hydrology –such as a potential deficit or excess in rainfall that results in a drought or flood. Subsequently, these hazards may have impacts or adverse effects on human systems (socio-economic) or in ecosystems (environmental services) with negative implications for the society.

Exposure was also defined in chapter 1 making reference to the social and material context represented by persons, resources, infrastructure, production, goods, services and ecosystems that may be affected by a hazard event. Exposure is related to the inventory of components of society and environment that are exposed to the hazard from spatial and temporal point of view (Cardona 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, population dynamics, 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 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 (UNISDR, 2009a).

Now, as defined in chapter 1, *vulnerability* refers to the propensity of exposed elements such as human beings and their livelihoods and assets –such as buildings and infrastructure– to suffer damage and loss when impacted by single or diverse hazard events (UNDRO, 1980; Cardona, 1986, 1990, 1993; Maskrey, 1993b; Liverman, 1990; Cannon 1994, 2006; Blaikie *et al.,* 1996; Weichselgartner, 2001; UNISDR, 2004, 2009b; Birkmann, 2006b; Janssen *et al*., 2006; Thywissen, 2006). In the context of disaster risk management, the early view of vulnerability was related to the physical resistance of engineered structures (UNDHA, 1992), but at present, vulnerability is related also to other facets, factors and levels that are generally seen as a result of defined social and environmental processes. Vulnerability in the context of disaster risk management is the most palpable manifestation of the social construction of risk (Aysan, 1993; Blaikie *et al.,* 1996; Wisner *et al.,* 2004) and is related, such as in the context of climate change, to the susceptibility, sensitivity and the lack of capacities to cope and adaptation of the exposed system (Luers *et al.,* 2003; Schröter *et al.,* 2005; Brklacich and Bohle, 2006; IPCC 2001, 2007). 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 the society reactions, prioritization and decision making processes.

The term vulnerability has been employed by a large number of authors in other contexts, to make reference to the environmental fragility of ecosystems for example or by social sciences to refer to disadvantaged conditions and circumstances and drivers that make people vulnerable to natural and economic stressors (Wisner et al. 2004, Brklacich and Bohle 2006, Villagran 2006). 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 (Wisner, 1993; Bankoff 2004b). 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 (Cannon, 2006; Cutter *et al*. 2008b). 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 (Lavell, 2005). 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, ecology, poverty studies, etc). A population might be vulnerable to hurricanes, for example, but not to landslides 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*., 2003a; Lopez-Calva and Ortiz, 2008; UN, 2009). From climate change perspective basic environmental conditions are supposed to progressively change over time and then induce new conditions for societies. For example, more frequent and more intense events may induce that territories that are not for the moment at risk would be in the future, and then their respective vulnerabilities will be revealed; in fact, their future vulnerability features are embedded in present conditions of the future exposed communities (Patt *et al*., 2005; 2009). An extensive review of the terminology was carried put by Thywissen (2006) and includes a long list of definitions used for the term vulnerability.

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). This means evidence of disaster risk and the occurrence of disasters have been constantly on the rise over the last five decades. This trend could continue, may be exacerbated and be further enhanced in the future as a result of projected climate change, unless concerted actions to reduce vulnerability and adapt to the changing climate are not enacted, including corrective and prospective interventions to address disaster risks (Lavell, 1996, 1999a, 2005; see chapter 3). From the research angle, natural and applied sciences (such as engineering) provide a basic platform and understanding of environmental processes (in terms of climatology, 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).

2.3. Vulnerability from a Social Viewpoint: Causal Factors

Overall, 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 the intrinsic predisposition to being affected, as well as the lack of capacities; conditions that favour or facilitate damage and loss. Many believe that it is not possible to fully 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, 1996a/b, 2004, 2010a). 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).

Vulnerability describes a set of conditions of people that derives from the cultural, 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 (Watts and Bohle 1993, 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) 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). 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). The integration of the environmental dimension of vulnerability is other relevant issue related to causes, because considers the links between communities and specific services and the vulnerability of ecosystem components to hazards (Renaud, 2006). Lastly, from climate change point of view, 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.

Due to the diversity of approaches to address the causes of vulnerability Twigg (2001), Birkmann (2005, 2006) and Villagran (2006) give an overview of conceptual frameworks, definitions and methods to characterize 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). Füssel and Klein (2006) review the evolution of the concepts and methods of vulnerability assessment in the climate change community. 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.

In addition, Thomalla *et al*. (2006) and Mitchell and van Aalst (2009) examine commonalities and differences between the climate change adaptation and disaster risk management 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 and projected changes.

In summary, from the abovementioned efforts, four approaches to understand vulnerability and its causes can be distinguished between those that are rooted in: political economy, social-ecology, vulnerability and disaster risk assessment from a holistic view, and climate change systems science.

a) Pressure and release (PAR) model (Blaikie *et al*. 1994, 1996; Wisner *et al*. 2004) is common to social science related vulnerability research and makes emphasis on the social conditions of exposure and the root causes that generate unsafe conditions. This approach links vulnerability to unsafe conditions in a continuum of vulnerability that connects local vulnerability to wider national and global shifts in the political economy of resources and political power.
b) The social-ecology perspective emphasizes the need to focus on coupled human-environmental systems (Hewitt and Burton, 1971; Turner *et al*. 2003). This perspective stresses transformative qualities of society for nature – and also the effects of changes in the environment for social and economic systems. It argues that the exposure and susceptibility of a system can only be adequately understood if these coupling processes and interactions are addressed.
c) Holistic perspectives from vulnerability have tried to extend from technical modelling to embrace a wider and comprehensive explanation of vulnerability. These approaches differentiate as causes or factors of vulnerability the fact to be exposed, susceptibility and societal response capacities (see Cardona 1999a,b; 2001, 2010; Cardona and Hurtado 2000a,b; Cardona and Barbat 2000; Bogardi and Birkmann 2004; IDEA 2005; Birkmann 2006b; Carreño 2006; Carreño *et al*. 2007a,b, 2009; Birkmann and Fernando 2008). A core element of these approaches is the feedback-loop that underline that vulnerability is dynamic and is the main driver and determinant of current or future risk.
d) In the context of climate change adaptation vulnerability is understood as a function of exposure, sensitivity and adaptive capacities (McCarthy *et al*. 2001; Brooks, 2003; Füssel and Klein 2006; Füssel 2007; IPCC 2007; O'Brien *et al*. 2008a,b). These approaches differ from the understanding of vulnerability in the disaster risk management perspectives as the rate and magnitude of climate change is considered. The concept of vulnerability here includes external environmental factors of shock or stress. Therefore, in this view, the magnitude and frequency of potentially hazard events is to be considered in the vulnerability to climate change. This view also differs in its focus upon long-term trends and stresses rather than on current shock forecasting, something not explicitly excluded but rather rarely considered within the disaster risk management approaches.

Taking into account that the measurement of vulnerability is a challenge and using the more compatible approaches of the above mentioned frameworks the MOVE project (Methods for Improvement of Vulnerability Assessment in Europe) addresses vulnerability and disaster risk to natural and socio-natural hazards, emphasizing the association of risk assessment, risk reduction, adaptation and decisionmaking (see Figure 2-1). It provides a summary of the causal and intervention aspects associated with this holistic vision of risk and vulnerability including adaptation as a key component of disaster risk management (Birkmann et al. 2011).

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

Understanding vulnerability requires, hence, 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 also 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.

The degree of vulnerability of the society 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 specific 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 hurricane winds is not necessarily the same as in relation to 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.

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; Adger 2006, Cutter *et al.,* 2008a,b; Décamps, 2010). In any case it refers to susceptibilities or fragilities of the exposed elements; i.e. to the likelihood to be affected. Vulnerability is closely tied environmental degradation, in both urban and rural contexts. This degradation may include local effects of global climate change.

Some global processes are particularly significant drivers of risk and are particularly related to vulnerability. These include population growth, rapid and inappropriate urban development, international financial pressures, increase in socioeconomic inequalities, environmental degradation, and global warming. To take but a limited number of examples, urbanization of prone areas has been an important factor in damage; population growth 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, 1996; Glade, 2003; Wisner et al. 2004, Bradshaw et al, 2007).

At least the common causal factors of vulnerability, according to disaster risk management and climate change adaptation communities, have been differentiated as follows (Cardona, 1999a/b, 2001, 2010a; Cardona and Barbat, 2000; Cardona and Hurtado, 2000a/b; Gallopin 2006, Carreño *et al.*, 2007a, 2009; McCarthy *et al.,* 2001; IPCC, 2007; ICSU-LAC, 2010; MOVE 2010):

- *Susceptibility (sensitivity)*: physical predisposition of human beings, infrastructure and environment to be affected by a dangerous phenomenon due to its lack of resistance and location (the fact to be exposed) in the area of influence of hazard.
- *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 and adaptive 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.

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 issues such as social inequalities regarding income, age or gender, as well as other characteristics of the society and the infrastructure, such as the level of urbanisation, growth rates, economic development, etc. (Cutter *et al*., 2003).

In summary, risk understanding depends on the understanding of how vulnerability can be captured in its different dimensions and causes, and taking into account that vulnerability correlates with susceptibility (including the physical characteristics of the built environment) and the ecological, social-cultural and socio-economic fragilities. In addition, vulnerability is heavily influenced by 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 context of climate change 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 1993a; Lavell 2005, Birkmann 2006a/b).

2.4. Coping and Adaptive Capacities

Capacity is an important element in most conceptual frameworks of vulnerability and risk. It refers to the positive features of people's characteristics that may reduce the risk posed by a certain hazard. Improving capacity is often identified as the target of policies and projects, based on the notion that strengthening capacity will eventually lead to reduced risk. Capacity clearly also matters for reducing the impact of climate change (e.g., Sharma and Patwardhan, 2008).

This section discusses the role of capacity in managing and reducing risk. It introduces the different aspects of capacity, the drivers and barriers of capacity, and discusses how to move from building capacity to applying it in practice. IPCC AR4 covered elements of adaptive capacity, options and constraints (Adger et al., 2007). This section extends that discussion by focusing on the role of capacity in exposure and vulnerability reduction, and by comparing coping and adaptive capacity (as introduced in Section 1.4).

As presented in Chapter 1, coping is typically used to refer to *ex post* actions, while adaptation is normally associated with *ex ante* actions. This implies that coping capacity also refers to the ability to react to and reduce the adverse effects of experienced hazards, whereas adaptive capacity refers to the ability to anticipate and transform structure, functioning or organisation to better survive hazards (Saldaña-Zorrilla, 2007). Presence of capacity suggests that impacts will be less extreme and/or the recovery time will be shorter, but high capacity to recover does not guarantee equal levels of capacity to anticipate. In other words, the capacity to cope does not infer the capacity to adapt, although coping capacity is often considered to be part of adaptive capacity (Levina and Tirpak, 2006). This section discusses adaptive and coping capacity through this lens, to understand whether there are different requirements for enhancing each of these types of capacity.

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Box 2-1. Coping and Adaptive Capacity: Different Origins and Uses

As set out in Section 1.4, there is a difference in understanding and use of the terms coping and adapting. 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, which has a different meaning in the climate change discourse.

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. 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 (Anderson and Woodrow, 1989). 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 rather than to just overcome them. 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).

_____ END BOX 2-1 HERE _____

2.4.1. Capacity and Vulnerability

The generation of risk studies prevalent prior to the 1990s placed focus mainly on hazards, and 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 act *ex post* and *ex ante*.

Many approaches for assessing vulnerability rely on an assessment of 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 concept of capacity 'played a pivotal role in the progressive emergence of the vulnerability paradigm within the scientific realm'. On the whole, the literature describes the relationship between vulnerability and capacity in two ways, which are not mutually exclusive (Gaillard, 2010; Smit and Wandel, 2006; Brooks et al, 2005; Downing and Patwardhan, 2004; Yodmani, 2001; Moss et al 2001; IPCC TAR, 2001):

1) Vulnerability is, among other things, the result of lack of capacity; and
2) Vulnerability is the opposite of capacity, so that increasing capacity means reducing vulnerability, and high vulnerability means low capacity.

There is also the notion that there is no relationship between capacity and vulnerability. This can be explained if the factors that drive vulnerability are unrelated to the factors that drive capacity, and increasing capacity has no direct impact on vulnerability, or vulnerability can be reduced without any change in capacity.

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-capacity assessment approach (VCA) (Davis *et al*., 2004; Anderson and Woodrow, 1989). Weighing vulnerability and capacity against each other has not always been part of the process of response and recovery, however. Anderson and Woodrow (1989) 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.

2.4.2. Different Capacity Needs

Risk reduction initiatives are typically framed around using existing 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 the capacity needs for risk reduction. As the previous section has pointed out, there are *ex ante* and *ex post* capacity needs. The capacity necessary to anticipate and avoid being affected by an extreme event requires different assets, opportunities, social networks, local and external institutions from capacity to deal with impacts and recover from them (Lavell, 1994; Lavell and Franco, 1996; Cardona, 2001, 2010a; Carreño et al, 2007a/b; ICSU-LAC, 2010; MOVE 2010). Capacity to change relies on yet another set of factors. Importantly, however, these dimensions of capacity are not unrelated to each other: the ability to change is also necessary for risk reduction and response capacities.

Just like vulnerability, capacity is dynamic and will change depending on circumstances. 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 (e.g., Cutter *et al*., 2008; Marulanda *et al.,* 2008b, 2009, 2010).

The discussion in BOX 2-1 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 suggests that work done to understand the drivers of adaptive – *ex ante* – capacity (Magnan, 2010; Sharma and Patwardhan, 2008; Vincent, 2007; Yohe and Tol 2002; Brenkert and Malone 2005; Brooks et al. 2005; Haddad 2005; Leichenko and O'Brien 2002) may have little to offer regarding *ex post*. Notably, the body of literature on the drivers of coping capacity is much more limited. This section discusses capacity needs based on the differentiation made between coping and adaptive capacity, thus this section explores capacity needed to reduce risk, respond to impacts, and change. Many of these elements are reflected in local, national and international context in chapter 5, 6, and 7 of this Special Report.

2.4.2.1. Capacity to Anticipate and Reduce Risk

Having the capacity to reduce the risk posed by hazards and changes implies that people's ability to manage is not engulfed, so they are not left significantly worse off. Reducing risk means that people do not have to devote substantial resources to dealing with a hazard as it occurs, but instead have the capacity to anticipate this sort of event. This is the type of capacity that is necessary in order to adapt to climate change, and involves conscious, planned efforts to reduce risk. Anticipating hazards goes beyond warning and preparedness and includes other explicit *ex ante* risk prevention and reduction actions; i.e. daily decisions and actions to reduce both vulnerability and exposure to hazard events. The capacity to reduce risk also depends on *ex post* actions, which involve making choices after one event that reduce the impact of future events.

Risk and risk factors are always present and may be the subject of conscious human modification, reduction or control. Capacity for 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*, 2003a). This can range from guaranteeing survival to the ability to secure future livelihoods (Eriksen and Silva, 2009; Batterbury, 2001).

Development planning, including land-use and urban planning, river basin and land management, hazard-resistant building codes and landscape design are all activities that can reduce exposure and vulnerability to hazards and change (Cardona, 2001, 2010a). The ability to carry these out in an effective way is part of the capacity to reduce risk. Other activities include diversifying income sources, maintaining social networks, and collective action to avoid development that put people at higher risk (Maskrey, 1989, 1994b; Lavell, 1994, 1999b, 2005). Successful *ex ante* strategies are closely linked with sustainable development pathways that go beyond a focus on resilience and instead aim for transformation (Pelling, 2010).

Capacity to reduce risk also depends on capacity to prepare for an extreme event. This form of risk management differs from anticipatory risk prevention and reduction because it focuses on the occurrence of hazards of exceptional magnitude that are not expected on a daily basis. Preparedness includes monitoring of hazards and dissemination of information and warnings (including early warning), having emergency plans and accessible evacuation information (including maps, shelters, emergency supplies), that facilitate making rapid choices to reduce both short- and long-term impacts. Due to the uncertain nature of these events and the costs associated with *ex ante* actions, there are limits to the sort of preparedness that can be taken on the local level. In Bangladesh, for example, storm shelters have been widely successful for saving lives during cyclones, but this type of investment is not feasible for the household of village level (Cannon, 2008).

Up to the beginning of the 1990s, disaster preparedness and humanitarian response dominated disaster practice, and focus on capacity was limited to understanding inherent response capacity. Thus, emphasising capacity to reduce risk was not a priority. 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, there is an increasing recognition of the need to promote the capacity for 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 reduce 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

Capacity to respond is relevant both *ex post* and *ex ante*, since it encompasses everything necessary to be able to react once an extreme event takes place. Although response capacity is mostly used to refer to the ability of institutions to react following a natural hazard, in particular ex-post emergency response. However, effective response requires substantial ex-ante planning and investments in disaster preparedness and early warning (not only in terms of financial cost but particularly in terms of awareness raising and capacity building). Furthermore, there are also response phases for gradual changes in ecosystems or temperature regimes caused by climate change. These response phases may be longer, but still require the capacity to overcome something new, different and/or unexpected. The response phase is when people are reacting to the impacts of either a hazard event or a change in climate. During this time, people are either coping with the impacts or beginning to adjust to experienced changes, or both. In adaptation terms, this is when 'reactive' adaptation occurs (Smit *et al*, 2001) – both planned and spontaneous. Responding spans everything from people's own initial reactions to a hazard upon its impact to actions to try to reduce secondary damage. It is worth noting that in climate change literature, anticipatory actions are often referred to as responses, which differs from the way this term is used in the context of disaster risk, where it only implies the actions taken once there has been an impact.

Since responding involves both affected people's actions as well as external assistance, capacity to respond is driven by several different factors and actors, but 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 may even leave people worse off than before (DfID, 2004; Anderson and Woodrow, 1989; 1991).

Capacity to respond is not sufficient to reduce risk. Humanitarian aid and relief interventions have 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, 2006). This does not only have implications for the capacity to respond, but also for other aspects of capacity. 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 responding, rather than on the capacity to reduce risk and change. Response capacity is also differential (Chatterjee, 2010).

At the same time, optimal risk reduction will generally not eliminate risk completely (particularly for the tail end of the distribution of hazard events, where the cost of risk reduction may well be prohibitive), so the most effective ex-ante risk management strategies will often include a combination of risk reduction and enhanced capacity to respond to impacts (including smarter response by better preparedness and early warning, as well risk transfer such as insurance).

2.4.2.3. Capacity to Recover and Change

Having the capacity to change is a requirement in order to adapt to climate change. Viewing adaptation as requiring transformation, implies that it cannot be understood as only a set of actions that physically protect people from natural hazards (Pelling, 2010). In the context of natural hazards, the opportunity for changing is greatest during the recovery phase, when physical infrastructure has to be rebuilt and can be improved, and behavioural patterns and habits can be contemplated (Birkmann *et al*, 2008). This is an opportunity to rethink whether the crops planted are the most suited to the climate and whether it is worthwhile rebuilding hotels near the coast, taking into account what other sorts of environmental changes may occur in the area. The ability to recover in a more resilient way also requires capacity to recover.

Capacity to recover is not only dependent on the extent of a physical impact, but also on the extent to which society has been affected, including the ability to resume livelihood activities (Hutton and Haque, 2003). This capacity is driven by numerous factors, including mental and physical ability to recover, financial and environmental viability and political will. 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, which brings change – but not necessarily change that leads to sustainable development. 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, to markets or roads, to the sea (e.g. South and Southeast Asia after the 2004 tsunami). There are also social reasons why people return to the same location, even if they are aware of the risks. The poorer people become, the more likely that natural hazards have a lower priority than the threats of homelessness, lack of employment, illness and hunger (Hutton and Haque, 2003; Maskrey, 1994b).

Recovering to return to the conditions before a natural hazard occurs not only implies that the risk may be the same or greater, but also does not question whether the previous conditions were desirable. In fact, recovery processes are often are out of synch with the evolving process of development (Mitchell, 2008). 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). Pushing the recovery towards transformation and change requires taking a new approach rather than returning to 'normalcy'. 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, however undesirable.

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 long-term preparedness and change (Christoplos *et al*, 2010).

Traditional understandings of the capacity to recover do not implicitly or explicitly aim for change, and thus the capacity change is not an expected component of the recovery process. Recent work has shown that this paradigm needs to be rethought, because the very occurrence of a disaster shows that there are gaps in the development process (UNDP, 2005). Lessons learned from studying the impacts of the 2004 Indian Ocean tsumani (Thomalla *et al*, 2009; Thomalla *et al*, 2010) can be applied also to climate-related hazards. They 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 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.
- 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

When people repeatedly have to respond to natural hazards and changes, the capitals that sustain capacity are broken down, increasing vulnerability to hazards (Wisner and Adams, 2003; Marulanda *et al*., 2008b, 2009, 2010; United Nations, 2009). Much work has gone into identifying what these factors of capacity are, to understand both what drives capacity as well as what acts as a barrier to it (Adger et al, 2004; Sharma and Padwardhan, 2008).

Drivers of capacity include: an integrated economy; urbanisation; information technology; attention to human rights; agricultural capacity; strong international institutions; access to insurance; class structure; life expectancy, health and well-being; 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 (Klein, 2001; Brooks et al, 2005; Barnett, 2005; Handmer et al, 1999; Cannon, 1994). Barriers to capacity include the lack of enabling drivers and determinants.

As a way of understanding the dimensions 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 it (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). Resources may be for enhancing 'the capacity and endurance of the affected people to cope with adversities' (Ahmed and Ahmad 2000: 100), but equating vulnerability with poverty creates a false association between lack of development and lack of capacity (Magnan, 2010).

Access to and the availability of financial, natural and social resources are 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 decision-making, and political feasibility.

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.

The capacity to respond through coping mechanisms may not enable adaptation, but there may be links between the factors that enable people to cope and those that allow them to adapt. While coping strategies such as selling off assets during drought can provide immediate relief – and this sense the ability to sell assets represents a degree of coping capacity – there is evidence that this will ultimately be damaging and increase vulnerability to future hazards for a number of reasons, (Corbett, 1988; Frankenberger and Golstein, 1990; Davies, 1996), thus decreasing adaptive capacity.

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. The definitions and applications of the, sometimes confounded, terms exposure and vulnerability, 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 but the distinction between them is often not made explicit.

O'Brien *et al*. (2008) contrast a hazard-centred, 'physical vulnerability' approach, emphasizing the bio-geo-physical and technological interpretations of vulnerability, with a complex interaction of biophysical, social, economic, political, institutional, technological and cultural conditions which is constitutive of a general 'social vulnerability' approach (2008: 13). 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 of conceptual obfuscation 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. Vulnerability is *implicit* in the conditions of "famine", "food insecurity" and "hunger". In these cases, vulnerability is inherent and not a predictor of a future situation; the predictors or stressors might be drought, undernutrition, or a number of other forms of deficit. The distinctions are important not only for conceptual clarity but for understanding the policy implications which otherwise may confuse a focus on symptoms with one on causes.

This section aims to be reasonably comprehensive without being exhaustive. The discussion is organized under the following main headings (with important sub-headings) to reflect major research foci but recognizing some significant overlaps:

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

The discussion begins with physical (and environmental) aspects because it is here that a major difference lies between those working primarily on climate change and those working from within the vulnerability paradigm of the disaster risk reduction community. Some in the latter group argue that it is only human beings that can be vulnerable; physical elements are simply exposed elements. For completeness, we include a discussion of the physical dimension and aim to bring out these distinctions in the process.

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 dimensions discussed here refer explicitly to a location-specific context for human–environment interaction (Smithers and Smit 1997, 131) in which 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) or exposure.

The physical *exposure* of human beings to hazards has been partly shaped by patterns of settlement on flood plains and other hazard-prone landscapes for the countervailing benefits they offer (UNISDR 2004). This does not make the inhabitants of such locations vulnerable per se because they may have capacities to resist the impacts of extreme events. 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). Physical vulnerability comprises aspects of geography, location, place (Wilbanks, 2003); settlement patterns; and physical structures (Shah, 1995; UNISDR, 2004) including infrastructure located in hazard prone areas or with deficiencies in resistance or susceptibility to damage (Wilches-Chaux 1989). 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.

2.5.1.1. 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, in the greatest number, who are 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 major distributional aspects of climate change. In a more targeted way, 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 at potential risk are threatened systems confined to narrow geographical ranges (McCarthy *et al.,* 2001) and less clearly delineated trade corridors (see the *economic* dimension below) which are extended, cross boundary regions vulnerable to the impacts of extreme events. Temperature and precipitation changes arising from climate change can be expected to have both positive and negative impacts on specific locations around the world. Such changes may lengthen the growing period (Menzel et al 2008; Christidis et al 2007) 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 developing the analysis of a generalised changed condition to a more specific 'vulnerability to hunger' in an African context.

Highly exposed 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; Nicholls 2004; Pelling and Uitto 2001). However, the point at which the disaster risk reduction literature can contribute to the understanding of the climate change adaptation community is in the recognition that the most biophysically exposed locations may not always intersect with the most vulnerable populations (Cutter *et al.,* 2000).

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; Scoones 1998).

Rapid urbanization processes have been shown to create vulnerability 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. Additionally, social isolation, especially as it intersects with individual characteristics (see Chapter 9, section 9.3.1, Case Study 9.2) and other social processes of marginalization (Duneier 2004), plays a significant role in vulnerability creation (or, conversely, reduction).

The built environment can be both protective of, and subject to, climate extremes. It is both vulnerability perpetrator and 'victim'. Inadequate structures make victims of their occupants but 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), 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 (and the wider supportive infrastructure necessary for their continued operation) 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). In a changing climate, more variable and with potentially more extreme events, old certainties about the protective ability of built structures are undermined.

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 may not be adequate for an existing rising trend in (particularly night-time) temperatures and thus will require recognition and attention in the context of longer term climate change adaptation (Shimoda, 2003). In a 1996 paper, Lavell identified eight contexts of cities that increased or contributed to disaster risk and vulnerability: the synergic nature of the city and the interdependency of its parts; the lack of redundancy in its transport, energy and drainage systems; territorial concentration of key functions and density of building and population; mislocation; social-spatial segregation; environmental degradation; lack of institutional coordination and the contrast between the city as a unified functioning system and its administrative boundaries that many times impede coordination of actions (Lavell 1996). There is utility in revisiting these in a context of climate change.

Many rural livelihoods are reliant to a considerable degree on the environment and natural resource base (Scoones 1998), and extreme climate events can impact severely on the agricultural sector (Saldaña-Zorrilla 2007). However, despite the separation here, the urban and the rural are inextricably linked. Inhabitants of rural areas are often dependent on cities for employment, as a migratory destination of last resort, and for health care and emergency services. Cities depend on rural areas for food, water, labour, ecosystem services 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). Furthermore, there is not a direct and inevitable link between disaster impact and increased impoverishment of a rural population. As Jakobsen found in Nicaragua (Jakobsen 2009), a household's probability of being poor in the years following Hurricane Mitch was not affected by whether it was living in an area struck by Mitch but by factors such as off-farm income, household size and access to credit. Successful coping post-Hurricane Mitch resulted in poor households regaining most of their assets and resisting a decline into a state of extreme poverty. However, longer-term adaptation strategies, which might have lifted them out of the poverty category, eluded the majority.

In assessing the material on exposure and vulnerability to climate extremes in urban and rural environments it is clear that there is no simple, deterministic relationship but one which is, or can be, either ameliorated or exacerbated by positive or negative adaptation processes.

2.5.2. Environmental Dimensions

The environmental dimension can include consideration of: 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); *impacts* to these systems (e.g. flooding of coastal cities and agricultural lands or forced migration); and/or the *mechanisms* causing impacts (e.g. disintegration of particular ice sheets) (Schneider *et al.,* 2007: 783; Füssel and Klein, 2006).

Maladaptive socio-ecological relations can expose people to hazards and increase their vulnerability to extreme events.

While there is valuable and necessary research on biophysical aspects alone, for the purposes of vulnerability analysis in the context of this special report, it is imperative to consider the mutuality between the environment and human beings; what has come to be called the socio-ecological system or SES (Gallopin et al 2001) approach. The SES approach grows out of a conception and an evidence base identifying fundamental errors in natural resource polices built on an assumption that human/social and environmental/ecological systems can be treated independently. This evidence base suggests that "natural and social systems behave in nonlinear ways, exhibit marked thresholds in their dynamics, and that social-ecological systems act as strongly coupled, complex and evolving integrated systems" (Folke et al 2002: 437). It points to the key links between property rights (Adger, 2000), development, environmental management, disaster reduction (e.g. Van Aalst and Burton, 2002) and climate adaptation.

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 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) (although Renaud (2006: 119-120) highlights the difficulty of accurately confirming attribution in some claims). Similarly, increasing location of housing in fire-prone areas is giving rise to greater human and property damage from San Francisco (Wisner, 1999) to Melbourne (see Box 4-2. Evolution of Climate, Exposure, and Vulnerability – The Melbourne Fires, 7 February 2009). Destruction of forest and other habitat on steep slopes exacerbates erosion of productive soils and amplifies exposure to landslide risks (Blaikie at al 1994; Glade, 2003; Wisner 2004, Bradshaw et al, 2007). The extent to which this exposure leads to or exacerbates vulnerability requires further analysis of local conditions in which some groups or locations are less able to anticipate, cope with or recover from disasters.

The vulnerabilities arising from floodplain encroachment and increased hazard exposure 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 and exposure in floodplains can put not only the lives and property of human beings at risk but can damage floodplain ecology and associated ecosystem services. Increased exposure of human beings comes about even in the face of actions designed to reduce the hazard. Structural responses and mitigation (e.g. provision of embankments, channel modification and other physical alterations 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 leads to increased flood risk and, ultimately, flood damages (see Figure 2-2). This maladaptive policy response to such exposure provides structural flood defences which encourage the belief that the flood risk has been removed. This then encourages more floodplain encroachment and a reiteration of the cycle as the flood defences (built to a lower design specification) are exceeded. This is typical of many maladaptive policy responses, which focus on the symptoms rather than the causes of poor environmental management. Any structural defence will have an exceedence probability, choices to provide protection for low consequence/return events will leave people and property at considerable risk of high consequence, extreme events.

[INSERT FIGURE 2-2 HERE:
Figure 2-2: Reactive and maladaptive policy responses: the ‘levee effect’ in floodplain hazard exposure.]

“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” (ICSU-LAC, 2009); see also Lavell, 1999a).

2.5.3. Economic Dimensions

This dimension includes economy as a *hazard* – a trigger for an extreme event (e.g. turbulence in (global) financial markets may lead to disaster for vulnerable groups); as an *outcome* of an extreme event (e.g. where an economy (at a particular scale) may be impacted by an event); and as a *condition* of vulnerability to an extreme event (e.g. where an economic system is such that it lacks resilience 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.

[INSERT TABLE 2-1 HERE:
Table 2-1: 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, 2004; Mechler, et al, 2010) and refers to the inability 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 (Mechler 2010). 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 hazards, 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 and social systems (Dudasik 1982) 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).

Paavola's (2008) analysis of livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania is indicative of the way extreme events impact livelihoods in specific ways. Here, rural households are found to be more vulnerable to climate variability and climate change than are those in urban environments. This is because rural incomes and consumption levels are significantly lower, there are greater levels of poverty, and more limited access to markets and other services. More specifically, women are made more vulnerable than men because they lack access to livelihoods other than climate-sensitive agriculture. Local people have employed a range of strategies (extensification, intensification, diversification and migration) to manage climate variability but these have sometimes had undesirable environmental outcomes, which have increased their vulnerability. In the absence of opportunities to fundamentally change their livelihood options, we see here an example of short term coping rather than long-term climate adaptation (page 651).

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 (in both wealthy and less wealthy countries) 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 often crosscutting. It encompasses aspects of several of the dimensions discussed above (e.g. that related to housing/built environment and work/livelihoods). 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 psychological trauma in and after disasters (e.g. Few, 2007), including that related to family breakdown and loss. The social dimension includes the following elements which will be elaborated below: education, health and well-being, culture, institutions, governance, including social networking and social capital/assets.

2.5.4.1. Education

The education dimension ranges across the vulnerability of educational building structures; issues related to access to education; and also sharing and access to information and knowledge (UNISDR 2006). 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 (UNDP 2004; UNICEF 2009). 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 of vulnerability includes differential health effects of extreme events 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, health service provision (e.g. environmental health and public health issues, infrastructure and conditions (Street et al., 2005)), which may be impacted by extreme events (e.g. failures in hospital/health centre building structures; inability to access health services because of storms and floods). Furthermore, mental health impacts of extreme events have been studied. For example, with flooding an association between increased risk of mental health problems has been shown in both adults and children (Aherne et al 2005, Department of Health 2009). In particular, a longitudinal study showed an eight fold increased risk of depression with pre-flood depression (Ginexi et al 2000) and a cohort study showed a four fold increased risk of psychological distress in adults at nine months post event (Reacher et al 2004). Other studies show that flooding is associated with increased rates of common mental disorders which may continue for a year or more post event (Tunstall et al, 2006, Carroll et al, 2006).

Health vulnerability is the sum of all the risk and protective factors that determine the degree to which individuals or communities could experience adverse impacts from extreme weather events (Balbus and Malina 2009). Vulnerabilities can arise from a wide range of institutional, geographic, environmental, socioeconomic, biological sensitivity, and other factors, which can vary spatially and temporally. Biological sensitivity can be associated with developmental stage (e.g. children are at increased mortality risk from diarrheal diseases); pre-existing chronic medical conditions (e.g. diabetics are at increased risk during heatwaves); acquired conditions (e.g. malaria immunity); and genetic factors (Balbus and Malina 2009). Vulnerability can be viewed from the perspective of the population groups more likely to experience adverse health outcomes, or from the perspective of the public health and health care services required to prevent adverse health impacts during and following an extreme event.

Demographic, medical, and social factors that increase vulnerability to heatwaves include age (infants, children, and older adults); gender; outdoor workers; presence of certain chronic diseases; use of particular medications; clothing choices; access to and use of cooling; urban and rural poor in developed countries; and socioeconomic factors (Basu and Ostro 2008; Bouchama et al. 2007; Kjellstrom et al. 2009; Kovats and Hajat 2008; Medina-Ramon et al. 2006; O'Neill et al. 2003; Staffoggia et al. 2006; Vandentorren et al. 2006). Heatwave vulnerability varies geographically within and between cities; key factors in one analysis that explained within city vulnerability were social and environmental vulnerability, social isolation, use of air conditioning, and proportion of the population that is elderly and/or diabetic (Reid et al. 2009). Vulnerability also varies temporally, as shown by the 2006 heatwave in Western

Europe that resulted in lower mortality than the 2003 heatwave; this difference was attributed to increased awareness, implementation of a heatwave early warning system, and better preparedness (Fouillet et al. 2008).

Population groups vulnerable to other extreme weather events depend on the adverse health outcome considered. For example, in flooding events, children are at greater risk for transmission of fecal-oral diseases, and those with mobility and cognitive constraints can be at increased risk of injuries and deaths (Ahearn et al. 2005).

Public health and health care services required for preventing adverse health impacts from an extreme weather event include surveillance and control activities for infectious diseases, access to safe water and improved sanitation, food security, maintenance of solid waste management and other critical infrastructure, maintenance of hospitals and other health care infrastructure, provision of mental health services, sufficient and safe shelter to prevent displacement, and effective early warning systems (Keim 2008). Lack of provision of these services increases population vulnerability, particularly in individuals with greater biological sensitivity to an adverse health outcome.

Extreme weather events also can result in short-term increases in population vulnerability by, for example, increasing common mental disorders and posttraumatic stress syndrome following a flooding event (Ahearn et al. 2005) – see Box 2-2 below. Flooding can also widen health and social inequalities because people on low incomes are less likely to be able to afford insurance against risks associated with flooding, such as storm and flood damage (Marmot, 2010). A UK study of over 1200 households affected by flooding suggested that there were greater impacts on physical and mental health among more vulnerable groups and poorer households and communities (Werrity et al 2007).

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.

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Box 2-2. Health Impacts Reported by Disaster Victims (Source: Norris, 2001)

Norris' 3-part review of 177 articles found a range of disaster impacts on mental health and wellbeing. The samples were coded for:
Disaster type: 62% natural disasters, 29% technological disasters, and 9% mass violence; and
Disaster location: 60% USA, 25% other developed country, 15% developing country.

Seventy-four percent of the samples showed specific psychological problems:
Posttraumatic stress or PTSD was found in 65%;
Depression or major depression disorder was found in 37%;
Anxiety or generalized anxiety disorder was found in 19%;
Non-specific distress was identified in 39%;
Health problems/concerns (e.g. self-reported somatic complaints, verified medical conditions, increased taking of sick leave, elevations in physiological indicators of stress, declines in immune functioning, sleep disruption, increased use of substances) were identified in 25%;

9% showed minimal impairment, meaning that the majority of the sample experienced only transient stress reactions;
52% showed moderate impairment (prolonged but subclinical distress);
23% showed severe impairment (25% to 49% of the sample suffered from criterion-level psychopathology); and
16% showed very severe impairment (50% or more of the sample suffered from criterion level psychopathology).

Source: Norris, F. H. 2001: 50*,000 Disaster Victims Speak: An Empirical Review of the Empirical Literature, 1981 – 2001*. Report for The National Center for PTSD and The Center for Mental Health Services (SAMHSA), September 2001. Executive Summary. http://www.dhss.mo.gov/SpecialNeedsToolkit/General/disaster-impact.pdf

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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’ a ‘Safety Culture’ or an “Adaptation 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. Adger has argued that if appropriate risk reduction actions are to occur the key players must bear all the costs and receive all the benefits from their actions (Adger, 2009).

Traditional behaviours tied to local (and wider) tradition and cultural practices can increase vulnerability. For example, unequal gender norms that put women and girls at greater risk or traditional uses of the environment that have not adapted (or cannot adapt) to changed environmental circumstances. On the other hand, local or indigenous knowledge can reduce vulnerabilities too (Gaillard et al 2010; Gaillard et al 2008). Furthermore, cultural practices are often subtle and may be opaque to outsiders. The early hazards paradigm literature (White, 1974; Burton, Kates and White, 1978) referred often to culturally-embedded fatalistic attitudes, which resulted in inaction in the face of disaster risk. However, Schmuck-Widmann (2000), in her social anthropological studies of char dwellers in Bangladesh, revealed how a belief that disaster occurrence and outcomes were in the hands of God did not preclude preparatory activities. Perceptions of risk (and their interpretation by others) depend on the cultural and social context (Slovic, 2000; Oppenheimer and Todorov, 2006; Schneider *et al.,* 2007).

While crude interpretations of behaviour and attitude as fatalistic have been challenged, fatalism as a social psychological construct continues to have a function. For example, empirically, in understanding risk reduction strategies by the urban poor (Wamsley 2007); methodologically, as needing to be overcome through Community Risk Assessments (van Aalst et al, 2008); and theoretically, in Cultural Theory, attempting to explain how people interpret their world and define risk according to their worldviews: hierarchical, fatalistic, individualistic, and egalitarian (Douglas and Wildavsky, 1982).

Research on culture also includes 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); the role of religion in influencing positions on environment and climate change policy (eg. Kintisch, 2006; Hulme, 2009); and religion and vulnerability (Schipper, 2010; Chester, 2005; Elliott, 2006; Guth *et al.,* 1995).

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, interests and attitudes of different social groups (see below, Cross-Cutting Dimensions and Intersectionality).

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.

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. However, as Adger and Kelly (1999) point out, the state of vulnerability is defined by a specific population at a particular scale; thus 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, and one which can be an exemplar for the way many other marginalized groups are differentially impacted or affected by extreme events, has been on gender, and on women in particular (e.g., Neal and Phillips, 1990; Enarson and Morrow, 1998; Neumayer and Plümper, 2007). 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). The specific gender and climate change link has been even more recent (e.g. Masika 2002 and see the other articles in this themed issue). The research evidence emphasises the social construction of gendered vulnerability in which women and girls are often, although not always, at greater risk of dying in disasters, typically marginalized from decision making fora, and discriminated against in post-disaster recovery and reconstruction efforts. However, 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 which obscures the very significant active contributions that women make for example. Box 2-3 provides an example of significant women-led disaster risk reduction and climate change adaptation.

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

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Box 2-3. 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 exposed to many hazards; they belong to an ethnic group descended from African slaves which is socially, economically and politically marginalised; and they depend largely upon a subsistence economy, with a lack of education, health and other resources. However, despite these markers of vulnerability, the Garifuna women have organized to reduce their communities' exposure to hazards and vulnerability to disasters through the protection and development of their livelihood opportunities.

The women lead the Comité de Emergencia Garifuna de Honduras, which is a grassroots, community-based group of the Afro-Indigenous Garifuna that was developed in the wake of Hurricane Mitch in 1998. After Mitch, the Comité women repaired hundreds of houses, businesses and public buildings, in the process of which, women were empowered and trained in non-traditional work. They campaigned to buy land for relocating housing to safer areas, in which the poorest families participated in the reconstruction process. Since being trained themselves in vulnerability and capacity mapping by grassroots women in Jamaica, they have in turn trained 60 trainers in five Garifuna communities to carry out mapping exercises in their communities.

The Garifuna women have focused on livelihood-based activities to ensure food security by reviving and improving the production of traditional root crops, building up traditional methods of soil conservation, carrying out training in organic composting and pesticide use and creating the first Garifuna farmers' market. In collaborative efforts, sixteen towns now have established tool banks, and five have seed banks. Through reforestation, the cultivation of medicinal and artisanal plants, and the planting of wild fruit trees along the coast, they are helping to prevent erosion and reducing community vulnerability to hazards and the vagaries of climate.

The Garifuna women's approach, which combines livelihood-based recovery, disaster risk reduction and climate change adaptation, has had wide-ranging benefits. They have built up their asset base (human, social, physical, natural, financial and political), improving their communities' nutrition, incomes, natural resources, and risk management. They continue to partner with local, regional and international networks for advocacy and knowledge exchange.

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2.5.7. Interactions and Integrations

This section began by breaking down the vulnerability concept into its constitutive dimensions, 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).]

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 group typically (with obvious exceptions such as slow onset hazards such as drought or desertification) deal with fast onset events, in discrete, even if extensive, locations, requiring immediate action. The latter group typically focuses on conditions which occur in a dispersed form over lengthy time periods and which are much more challenging in their identification and measurement (Thomalla *et al.,* 2006: 41). Risk perception may be reduced (Leiserowitz, 2006: 52) for such events remote in time and/or space, such as some climate change impacts are perceived to be. Thus, in this conceptualisation, different time scales are an important constraint when dealing with the link between disaster risk reduction and climate change adaptation (see Birkmann and 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 which 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 or 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]

2.6. Vulnerability Profiles

2.6.1 Introduction

This section looks at the characterization of vulnerability of selected sectors (using the classification in the Fourth Assessment Report, IPCC, 2007). These are intended as examples of how vulnerability, as defined by the dimensions listed in section 2.5, plays out in specific sector contexts and can be summarized in vulnerability profiles. These vulnerability profiles discussion is indicative and by no means exhaustive with regard to factors or indicators of the sectors. The section also discusses difficulties and problems with vulnerability profiling.

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 assessed. In defining such a profile, which is often applied for a specific location or issue being addressed, a description of the vulnerable situation (who, what and where) is an important first step, followed by an analysis of vulnerability factors and constraints, and finally an evaluation of opportunities, which are the positive factors that exist internally in the system or in the external environment, which could potentially contribute to an improvement in performance or resilience.

Vulnerability profiling, as part of a larger environmental profiling, thus identifies key threats and weaknesses in a sector or system. Aside from establishing qualitative and quantitative baseline information, a vulnerability profile identifies data gaps that require further research or monitoring and enhances the awareness of stakeholders. The profile is essentially the basis for developing sector strategy and conducting initial risk assessment. The data collected through profiling are also useful inputs for the establishment of an integrated information management system (KMI, 20010).

2.6.2. Agriculture and Food Security

The increases in mean temperature and a decline in precipitation rates changes, in conjunction with changes in land use that result from urbanization and agriculture, are likely to impact substantially on food production and food security (Tong, et al, 2010). The overall impact of climate change on food security will depend on the socio-economic status of each affected country and the extent of climate change in different regions.

Although the potential impacts of climate change on rainfed agriculture vis-à-vis irrigated systems are still not well understood, climate change is expected to change the pattern and quantity of rainfall; evapotranspiration, surface run-off and soil moisture storage; and water availability for irrigated agriculture and public use. 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 hazards, 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.

The components of vulnerability include exposure to climate change induced threats resulting to possible impacts of sea level rise and coastal flooding (e.g., saline intrusion due to sea level rise and storm surges, lowered freshwater availability, soil erosion, and land degradation); high intensity rainfall events (e.g., soil erosion, siltation and landslides); low rainfall (e.g., prolonged droughts); rise in temperature(e.g., crop heat stress and high incidence of pest and diseases). There are also vulnerability enhancing factors that may increase vulnerability to climate change such as: moving away from the use of traditional varieties of crops; loss of traditional knowledge in agriculture; loss of agricultural production due to land degradation and land use change; and threats from invasive species. Vulnerability of the agricultural community to climate change will be influenced by several socioeconomic factors, including status of poverty and food security; insecurity of land tenure; amount of resource endowed; education levels; dependency on agriculture for livelihood; availability of irrigation water; institutional supporting framework and government policies.

One way of mapping vulnerability is to use geographical information system (GIS) generated indices: exposure, sensitivity, adaptive capacity and combining them to create a composite sector-specific vulnerability index (O'Brien, 2004; Gov't of Sri Lanka, 2010)). In Box 2-4, a sector vulnerability profile for Agriculture and Fisheries sector is presented as prepared by Sri Lanka to provide additional inputs to its National Climate Change Adaptation Strategy for 2011 to 2016.

___ START BOX 2-4 HERE____

Box 2-4. Mapping Vulnerability of Agriculture and Fisheries in Sri Lanka

Exposure indices for floods, drought, and landslide) - developed based on historical data on the frequency and scale (i.e. assessed in terms of number of people affected). The index for sea level rise was based on a ratio of the area of land within 2 m above sea level as a percentage of total land area within 5 km from the coastline. Topography data was obtained from ASTER 30 m Digital Elevation Model. These exposure indices are common across all sectors. However only exposure types relevant to a given sector were analyzed and illustrated.

Examples of generated sensitivity and adaptive capacity indices, which are unique to each sector and the indicators used in their formulation, are shown below. It must be noted that the mapping exercise itself is preliminary and limited in scope, and should be refined on a periodic basis, based on detailed data which may become available from time to time from various sources.

[INSERT TABLE 2-4 HERE:
Table 2-4: Examples of generated sensitivity and adaptive capacity indices for agriculture and fisheries in Sri Lanka.]

____END BOX 2-4 HERE____

2.6.3. Human Health

Nearly all the adverse environmental and social effects of climate change will ultimately threaten human health (physical, nutritional, microbiological, or mental), as shown in Table 2-5 (Filiberto et al., 2010). Food yields, water flows, air quality, supplies of various other natural resources, and direct impacts of climate extremes all affect population health—and may all be affected by climate change.

[INSERT TABLE 2-5 HERE:
Table 2-5: Possible health threats from climate change.]

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, effects on malnutrition and air quality. 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. 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; WHO, 2010). It is projected that with climate change, the number of people suffering from death, disease and injury from heat waves, floods, storms, fires and droughts would increase (Confalonieri et al, 2007).

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 successful public health policy and practice. This capacity building will help to reduce vulnerability 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.

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. 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.

____START BOX 2-5 HERE____

Box 2-5. Vulnerability of Human Health to Climate Change and Extreme Events (Confalonieri et al., 2007)

Floods and weather disasters
Floods are low-probability, high-impact events that can overwhelm physical infrastructure and human communities. Major storm and flood disasters have occurred in the last two decades. Vulnerability to weather disasters depends on the attributes of the person at risk, including where they live and their age, as well as other social and environmental factors. High-density populations in low-lying coastal regions experience a high health burden from weather disasters.

Heatwaves
Hot days, hot nights and heatwaves have become more frequent. Heatwaves are associated with marked short-term increases in mortality. For example, in August 2003, a heatwave in Europe resulted in excess mortality in the range of 35,000 total deaths.
Heat-related morbidity and mortality is projected to increase. The health burden could be relatively small for moderate heatwaves in temperate regions, because deaths occur primarily in susceptible persons.

Drought

The effects of drought on health include deaths, malnutrition, infectious diseases and respiratory diseases. Countries within the "Meningitis Belt" in semi-arid sub-Saharan Africa experience the highest endemicity and epidemic frequency of meningococcal meningitis in Africa, although other areas in the Rift Valley, the Great Lakes, and southern Africa are also affected. The spatial distribution, intensity, and seasonality of the epidemic appear to be strongly linked to climate and environmental factors, particularly drought. The cause of this link is not fully understood.

Fires

In some regions, changes in temperature and precipitation are projected to increase the frequency and severity of fire Forest and bush fires cause burns, damage from smoke inhalation and other injuries.

____END BOX 2-5 HERE____

2.6.4. Freshwater Resources

Climate change has wide-ranging and complex impacts on water resources. These impacts have potentially huge implications on the agricultural, drinking water and energy sectors, public health, and ecosystem functionality. While this is particularly true in the regions of the world least able to cope with the impacts of climate change, the water management challenges posed by climate change will be universal. Water and how it is managed, presents one of the more significant opportunities to enhance resilience and adapt to present and future climate variability. Groundwater is one important source of freshwater and its vulnerability can be indicated in several ways as in Table 2-6.

[INSERT TABLE 2-6 HERE:
Table 2-6: Examples of vulnerability indicators for freshwater resources (Collins and Bolin, 2007).]

2.6.5. Ecosystems

Climate variability and change can directly impact on ecosystem functions and services, as already observed in the current climate regime (Tong, et al, 2010). There is a high confidence probability that the resilience of many ecosystems will be undermined by climate change, reducing biodiversity, damaging ecosystems and compromising the services that they provide (IPCC, 2007).

Climate change, variability and extremes could intensify significant influences on ecosystems and alter services (beneficial resources and processes) they provide (IPCC, 2007; MEA, 2005). While life forms have adapted to their regional climate over time, abrupt changes in climate modify the resources and processes that they provide to society, and potentially can act as a factor that affects ecosystems. For example, humans depend on ecosystems for the natural, cultural, spiritual, and recreational resources they provide. Global warming can affect biological and ecological components of the ecosystem and can create new environmental conditions for humans and other organisms by changing and disturbing ecosystem dynamics [Tong, et. al., 2010; Parmesan, et al., 2003).

The vulnerability of a specific ecosystem is a function of time and space. These are related both to different climate pressures and community responses. The ecosystems most vulnerable to climate change are likely those that are already near important thresholds due to other driving variables, which may lead 9o the so-called regime shifts (Biggs, et al., 2008). For example, the case where water use competition is already occurring, high summer water temperatures could be a limit for some species of concern; or the case where there are human-induced stressors together with climate change, such as such as limited water availability from available sources due to more urgent needs for human activities Slight shifts in climate can also alter the boundaries of terrestrial ecosystems, plant compositions, and the rate of supply of organic matter, with resulting impacts on the health of aquatic ecosystems. Marine species (individuals and populations) are affected either directly through metabolic and reproductive processes or indirectly through the ecosystem, including prey, predators, and competitors (Stenseth, et al., 2002).

Transition zones, where species compositions alter dramatically, may show the earliest evidence of change, and the changes may not be gradual. Better information is needed on which ecosystems change gradually and which may be subject to dramatic or sudden changes when a threshold is reached. Understanding these responses would enhance the detection and prediction of climate change, variability and extremes to these systems.

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.

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 neither the environment nor society are static, exposure and vulnerability vary over time, with the result that two very similar extreme weather or climate event may cause very different impacts. In some cases, this results in substantial changes in risk. In fact, there is high confidence for several hazards, changes in exposure and in some cases vulnerability are the main drivers behind observed trends in disaster losses, and will be continue to be essential drivers of changes in risk patterns over the coming decades (e.g. Bouwer *et. al.*, 2007; Pielke and Landsea, 1998; UNISDR 2009).

Chapter 4 presents detailed quantitative information about these patterns, in the context of observed and projected impacts of extreme events in light of climate change. Unfortunately, good data and analysis on observed changes in vulnerability are lacking, which complicates attribution of trends in impacts to specific underlying causes. However, there are several underlying drivers, partly along the lines of the dimensions of vulnerability and exposure discussed in section 2.5, which clearly play a role in trends in disaster risk, although differently in different places and for different levels of spatial aggregation.

This section assesses the potential for, and presents where possible, the limited evidence for secular changes in factors related to the physical, economic social, science and technology and governance dimensions of exposure and vulnerability.

2.7.2. Physical Dimensions, Settlement Patterns, and Development Trajectories

The characteristics of the places where people live and where assets are located are key attributes in the vulnerability and exposure patterns that determine disaster risk. A full treatment of aggregate trends in the environmental dimensions of exposure and vulnerability as they related to geography, location and place are given in Chapters 3 and 4. This section discussed the related underlying changes in in settlement patterns and development trajectories that drive many changes in exposure and vulnerability at local, national and global scales.

Settlements are where people gather in varying densities to live. Urbanization has been an imporatnt trend in human settlement over the last five decades. For example the percentage urban population increased in Africa and Asia from 14 to 39 and 16 to 41 percent respectively over the period 1950 to 2009. While North America and Europe was already moderately urbanised in 1950, with an urban populations of 63 and 50 percent, by 2009 this had increased to 82 and 72 percent respectively. Globally the end of the first decade of the 21st century represents an important watershed for human settlement, as in 2008 just over 50 percent of the world's population lived in urban areas. By 2050 it is predicted that the world's urban population will reach 69 percent and that most of the growth will be concentrated in urban areas in less developed regions with Asia and Africa expected to have urban dwellers making up 61 and 64 percent of their region's total population respectively. Latin America and the Caribbean already have a highly urbanised population of 79 percent but by 2050 this region is expected to reach 89 percent, comparable to the 90 percent urban population expected for North America (United Nations, 2010).

Urbanization is of concern to disaster risk management and adaptation because of its implications for exposure and vulnerability. For a variety of reasons, extreme events can cause a large loss of life or livelihoods when these events occur in places with high concentrations of people (Guha-Sapir, D. et al., 2004). The devastating impacts of Hurricane Mitch in Central America in 1998 and Hurricane Katrina in 2005 are clear demonstrations of how settlements in developing and developed countries located in hazardous locations are highly vulnerable to acute extreme storm and flood events (Fungfeld, 2010). The 2009 Melbourne heat wave provides a lucid example of how a pervasive meteorological event can impact a heavy toll on life and infrastructure in a large city which was thought to have a relatively good level of preparedness for extreme climate events (QUT, 2010).

On the other hand, the spatial concentration of people might also allow for improved capacities to cope and to adapt. Cross (2001) argues that small cities and rural communities are more vulnerable to disasters than big cities or megacities, since megacities have considerable resources for dealing with hazards and disasters. For that reason, contrary to what is often assumed, urbanization is not always a driver for increased vulnerability. Instead, the type of urbanization and the context in which urbanization is embedded defines whether these processes contribute to an increase or decrease in people's vulnerability to natural hazards and changing environmental conditions.

In particular, vulnerability often increases in the case of informal urban settlements where poor people are concentrated and do not get access to service provision and basic needs, such as clean water. Also settlements that are located in areas prone to hydrometeorological hazards such as flood plains, low lying coastal zones and steep slopes are highly exposed and often a point where marginalized groups have to migrate to due to a lack of alternative locations or the fact that areas close to river systems or areas at the coast line are often state land that can be accessed compared to private land.

In addition, the rapid growth and expansion in those cities often leads to a loss of governability and a reduction in the capacity of formal players to steer developments and adaptation initiatives in a comprehensive, preventive and inclusive way. Particularly, the lack of service provision with respect, for example, sewage systems or effective transportation means for emergency response contribute among other factors to an increasing vulnerability to climate change impacts (see Birkmann et al. 2010)

Furthermore, in some regions the population that determines the major increase in urban population appears to be refugee populations. In 2009 the percentage of urban based refugees had reached 58 percent almost twice that living in camps and 8 percent higher than 2007 when for the first time refugees living in urban centres outnumbered those in non-urban areas (UNHCR, 2009).

While the rates of urbanisation are expected to slow in the developed world over the next 40 years, in the developing world total population growth will become largely an urban phenomenon (Satterthwaite, 2007). This has implications for possible trends in vulnerability and exposure as increasing numbers of people concentrate in existing urban centres built on flood plains and low coastal zones and marginal land where good land and infrastructure availability is restricted. Rapidly growing urban populations may also affect the capacity of developing countries to cope with the effects of extreme events because of the ability of governments to provide the requisite urban infrastructure and for citizens to pay for essential services (UN Habitat, 2009). This may be especially so for urban centres with less than one million population as these are expected to account for 63 and 54 percent of the increase in urban population between 2009 and 2025 in more developed and less developed regions respectively and are often of lower priority for government spending. This contrasts with mega-cities as between 2009 and 2025 they are expected to account for only 3 and 14 percent of the total urban population growth in more developed and less developed regions receptively (United Nations, 2010).

Associated with burgeoning urban populations are changes in urban form. As yet there has not been a systematic empirically based assessment of the implications of rapidly changing urban form for trends in exposure and vulnerability. However the potential for the disproportionate concentration of people in the region's largest cities and the trend to increasing levels of informal, unserviced and unregulated peri-urbanisation as found for Sub-Saharan urban centres and the relocation of people, industry and services to the urban periphery and associated rising cost of infrastructure and service delivery as found in many Latin Amercan cities (UN Habitat, 2010) might lead to temporal and spatial trends in exposure and vulnerability. Such trends may emerge due to highly differentiated urban landscapes in terms of exposure because of the location of dwellings/settlements in hazardous locations and the loss of ecosystems services arising from land use change and vulnerability due to social inequalities because of highly spatially differentiated infrastructure and service delivery all of which coalesce to raise the level of risk due to extreme climate events.

A number of country development trajectories have been identified (United Nations, 2009), namely high economic growth and high human development, neither high economic growth nor high human development and high growth in either economic or human development terms but not the other. The extent to which such trajectories have influenced historical trends in exposure and vulnerability have as yet not been assessed and room remains for a systematic research agenda on this potential association.

Globally the pressure for urban areas to expand onto flood plains and coastal strips has resulted in an increase in exposure of populations to riverine and coastal flood risk (Feyen et al., 2009; McGanathan et al., 2007; Nichols et al., 2008). For example intensive and unplanned human settlements in flood-prone areas appear to have played a major role in increasing flood risk in Africa over the last few decades (Di Baldassarre et al., 2010). As urban areas have expanded urban heat has become a management and health issue (see heat wave case study Chapter 9). There is strong observational evidence for increases in urban warming for some major cities and thus exposure of populations to extreme urban heat events (Fujibe, 2009; Kataoka et al., 2009; Stone 2007). 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) due to 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. Such changes in green space may increase exposure to extreme climate events in urban areas through decreasing runoff amelioration and urban heat island mitigation effects and alterations in biodiversity (Wilby and Perry, 2006).

Associated with rapid urbanisation are increases in the number and extent of informal settlements or slums (UN Habitat, 2003; Utzinger and Keiser, 2006) which are often located on marginal land within cities or on the periphery. Because of their location, slums are often exposed to hydrometeorological related hazards such as landslides (Nathan, 2008) and floods (Aragon-Durand, 2007; Bertoni, 2006; Colten, 2006; Douglas et al., 2008; Zahran et al., 2008). Vulnerability in informal settlements can also be elevated because of poor health (Sclar et al., 2005) and livelihood insecurity (Kantor and Nair, 2005). Lagos Nigeria (Adelekan, 2010) and Chittagong, Bangladesh (Rahman et al., 2010) serve as clear examples of where an upward trend in the area of slums has resulted in an increase in the exposure of slum dwellers to flooding. Despite the fact that rapid growing informal and poor urban areas are hotspots of vulnerability, it has to be acknowledged that also various urban poor have developed more or less successful coping and adaptation strategies to deal with changing environmental conditions (see e.g. Birkmann et al. 2010).

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 (Roth and Coelho, 2007). Alterations or trends in any of these components of the urban system, such as environmental governance or the percentage of people living in the low elevation coastal zone, could bring about changes in vulnerability and exposure. 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 exposure and vulnerability to extreme climate events substantially (Freudenberg et al., 2008). Similarly the continued reliance on insurance products as an adaptive strategy for managing urban flood risk 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).

2.7.3. 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).

Generally positive drivers are decreasing reliance of many developing economies on agriculture, which tends to be most sensitive to the impacts of extremes. However, narrow economic development paths focusing on a relatively limited range of economic activities may continue to result in relatively high vulnerability to shocks.

Finally, it should be noted that economic development is often resulting in an increasing reliance on critical infrastructure, such as power supply. Where this infrastructure is at risk of natural hazards, it may have large impacts on the functioning of economies as a whole.

2.7.4. Social Dimensions

2.7.4.1. Demography

Certain population groups may, in a relative sense, be more vulnerable than others to extreme climate events. For example, the very young and old are more vulnerable to heat than other population groups (Staffogia et al., 2006). Europe, where heat waves are a characteristic of the climate and the majority of heat related deaths occur amongst the elderly (Gosling et al., 2009), posseses one of the most rapidly aging populations with 16 percent of the population 65 or over in 2009 with this projected to increase to 37 percent in 2050 (United Nations, 2009b). Such a trend might lead to an increase in the pool of individuals susceptible to heat. The trend to an aging population is not restricted to Europe as the population of most countries is aging, Currently the percentage of people more than 60 years is higher in more developed compared to less developed countries; 20 compared with 8 percent. By 2050 it is expected that the percentage of older people will increase to 33 and 20 percent in more developed and less developed countries respectively. Although there is little evidence in the literature of concomitant secular changes in aging and vulnerability a rapidly aging population at the community to country scale bears implications for health, social isolation, economic growth, family composition and mobility all of which are social determinants of vulnerability.

Conceptually, trends in migration as a component of changing population dynamics could arise because of alterations in extreme climate event frequency. However because of the multi-causal nature of migration the role of climatic variability and change in migration is often contested (Black, 2001) as are the terms environmental refugee and climate refuges (Myers, 1993; Castles 2002, IOM, 2009). The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) and the Internal Displacement Monitoring Centre (IDMC) have estimated that 20,293,413 people were displaced or evacuated in 2008 because of climate-related disasters. (OCHA/IDMC, 2009). Further over the last 30 years, twice as many people have been affected by droughts as by storms (1.6 billion compared with approximately 718 million) (IOM, 2009). Despite an increase in the number of hydrometeorological disasters between 1990 and 2009, the International Organisation on Migration reports no major impact on international migratory flows because displacement is temporary and often confined within a region, plus displaced individuals do not possess the financial resources to migrate (IOM, 2009). Although there is also a lack of clear evidence for a systematic concomitant trend in extreme climate events and migration, there are clear instances of the impact of extreme hydrometerological events on displacement. For example floods in Mozambique displaced 200,000 people in 2001, 163,000 people in 2007 and 102,000 more in 2008 (INGC, 2009; IOM, 2009), in Niger large internal movements of people are due to pervasive changes related to drought and desertification trends (Afifi, 2010), in the Mekong River Delta region changing flood patterns appear to be associated with migratory movements (IOM, 2009; White, 2002) and Hurricane Katrina for which social vulnerability, race and class played an important role in outward and returning migration (Elliot and Pais, 2006; Landry et al., 2007; Meyers et al., 2008) resulted in the displacement of in excess of one million people. As well as the displacement effect there appears to be evidence for increased vulnerability to extreme events amongst migrant groups because of an inability to understand extreme event related information due to language problems, prioritisation of finding employment and housing and distrust of authorities tends (Donner and Rodriguez, 2008; Enarson and Morrow, 2000).

Although gender, race and class have been found to be important in determining vulnerability and the modification of risk to extreme climate events (Enarson and Fordham, 2001; Rodriguez and Russell, 2006), there is little evidence in the literature for secular vulnerability trends related to these social factors.

2.7.4.2. Education

As outlined in Section 2.5.4.1 the education dimension refers to educational building structures, access to education, natural hazards in the education curriculum and access to information and knowledge. In many disasters due to extreme events a major component that constituted the disaster was a lack of appropriate information and education. Where flooding is a recurrent phenomenon schools can be at risk to exposure to floods. For example a survey of primary schools' flood vulnerability in the Nyando River catchment western Kenya, revealed that 40% were vulnerable, 48% were marginally vulnerable and 12% were not vulnerable with vulnerability due to a lack of funds, poor building standards, local topography, soil types and inadequate drainage (Ocola et al., 2010). Although this study does not provide an assessment of trends in exposure or vulnerability, by considering changing flood frequency or the historical deterioration of buildings, in terms of the published peer reviewed literature, it is quite rare. This is indicative of the lack of information on trends in exposure and vulnerability of educational structures. The same applies to trends in access to education as might arise from school closures related to any observed increase in extreme weather event frequency.

Over the last 20 to 30 years there has been a trend in some countries towards incorporating environmental education into educational curricular at a variety of levels (Filho, 1996). Although the curricular content may not explicitly relate to extreme climate events, vulnerability and exposure 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.

Access to information related to early warnings, response strategies, coping mechanisms, science and technology, human, social and financial capital is critical for reduction of vulnerability and increasing 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) and belonging to a social network (Peguero, 2006). However there are no systematic studies on how these factors may have varied historically and thus given rise to any trends in exposure and vulnerability. Some evidence exists that people who have experiences natural hazards before are in general better prepared than those who have not. Thus information and experiences of hazards are a key factor that differenciates vulnerability in developing and developed countries. Furthermore, there is emerging evidence of a growing digital divide (Critcuer and Zook, 2009; Rideout, 2003) which may influence trends in vulnerability as an increasing amount of information about extreme event preparedness and response is often made available via the internet.

2.7.4.3. 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) may affect vulnerability and exposure to extreme events. Although there is little evidence for trends in the exposure or vulnerability of public health infrastructure the imperative for a resilient health infrastructure is widely recognised in the context of extreme climate events (Burkle and Greenough, 2008; De Salvo et al., 2008).

For some health outcomes, which have direct or indirect implications for vulnerability to extreme climate events, there is evidence of trends. For example obesity, a risk factor for cardiovascular disease, which in turn is a heat risk factor, has been noted to be on the increase in a number of developed countries (Skelton et al., 2009; Stamtakis et al., 2010). Observed trends in major public health threats such as the infectious or communicable diseases HIV/AIDS, tuberculosis and malaria, although not directly linked to the diminution of long term resilience of some populations, have been identified as having the potential to do so (IFRC, 2008). 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 as observed in some countries (Vitoria et al., 2009) may also contribute indirectly to increasing vulnerability and exposure 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; see also chapter 3) 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. Additionally, deteriorating environmental conditions and the degradation of environmental services and goods is particularly problematic for rural poor and rural communities which have often a direct dependency on ecological resources, such as clean water for drinking and farming (see Renaud 2006). Globally, particularly communities in low-laying coastal areas will suffer from salinization processes that will affect the availability or degradation of the access to clean water for drinking and farming. These trends are already observable e.g. in the Mekong Delta. Furthermore, the salinization has also a direct negative effect on the productive function of soils, thus ecosystem services are vulnerable to climate change.

2.7.5. Science and Technology

Over the last few decades there have been rapid advancements in science and technology especially in the agricultural sector. These have been functional in increasing food production, decreasing food prices and reducing famine. However a the beneficiaries of science and technology development are often unequally in distributed 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 science and technology transfer is required, the success of which will dependent on the ability of the recipient community to apply the transferred science and technology (Gisselquist et al., 2002; (IAASTD, 2009).

Although approaches alternative to pure science and technology based ones have been suggested for decreasing vulnerability (Haque and Etkin, 2007; Marshall and Picou, 2008), such as blending western science and technology with indigenous knowledge (Mercer et al., 2010) and ecological cautiousness and the creation of eco-technologies with a pro-nature, pro-poor and pro-women orientation (Kesavan and Swaminathan, 2006) there has not been any systematic scientific assessment of their efficacy to date.

The increasing integration of a range of emerging weather and climate forecasting products into early warning systems has helped reduce exposure to extreme climate events because of an increasing improvement of forecast skill over a range of time scales (Barnston et al., 2010; Goddard et al., 2009; Stockdale et al., 2009; van Aalst, 2009). Moreover, there is an increasing use of weather and climate information for planning and climate risk management in business (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).

2.7.6. Governance

Governance is also a key topic for vulnerability and exposure. Governance is broader than governmental actions, governance can be understood as the structures of common governance arrangements and processes of steering and coordination – including markets, hierarchies, networks and communities (Pierre and Peters 2000). Institutionalized rule systems and habitulized behaviour and norms that govern society and guide actors are representing governance structures (Ostrom 2005, Adger 2000, Biermann et al. 2009). These formal and informal governance structures are also determine vulnerability, since they influence power relations, risk perceptions and constitute the context in which vulnerability, risk reduction and adaptation are managed.

Particularly conflicts between formal and informal governance strategies and norms can generate additional vulnerabilities for communities exposed to environmental change. An example of these conflicts of formal and informal strategies is linked to flood protection measures. While local people might spend various resources to deal with increasing flood events in terms of adapting their livelihoods and production patterns to changing flood regimes, formal adaptation strategies in some countries particularly in so called developing countries are prioritizing structural measures, such as dyke systems or relocation strategies, that have severe consequences for the vulnerability of local communities depending on local ecosystem services, such as fishing and framing systems (see Birkmann 2011). These conflicts between formal and informal management and norm systems are an important factor that increases vulnerability and reduces adaptive capacity of the overall system (see e.g. Birkmann et al. 2010).

Increases in state governance deficits and respective implications for the vulnerability of people in these countries can also be assessed using performance indicators for governance policies and governance issues linked to the social, political and economic dimension of governance. At the international level governance issues can be described and measures examining governance problems, such as corruption or the progressive deterioration of public service provision or the widespread violation of human rights.

Countries classified as failed or fragile states often lack the capacity to deal with emergencies and disasters effectively due to governance problems. The recent disaster and problems in coping and recovery in the aftermath of the Earthquake in Haiti or the problems in terms of managing recovery and emergency management after the Pakistan floods are examples that illustrate the importance of governance as a subject of vulnerability.

Although it is still difficult to evaluate governance deficits at the international level, recent studies such as the Corruption Perception Index (CPI) published by Transparency International or the Failed States Index (FSI) published by Foreign Policy and Fund for Peace underline that in many countries heavily affected by natural hazards governance problems are likely to increase the vulnerability of people at risk. Despite the fact that trends are difficult to analyze, the examination of governance problems, linked to social indicators, such as mounting demographic pressures, massive movement of refugees or IDPs creating complex humanitarian emergencies, legacy of vengeance-seeking group grievance or group paranoia, chronic and sustained human flight, and secondly economic indicators, such as uneven economic development along group lines, sharp and/or severe economic decline and thirdly political indicators such as criminalization and/or delegitimization of the State, progressive deterioration of public services, suspension or arbitrary application of the rule of law and widespread violation of human rights are key factors that show the context in which the vulnerability of individuals is embedded and underlines the lack of these countries to provide services that can help to reduce vulnerability and increase resilience, particularly of the poorest communities and groups.

Moreover, the World Bank has been issuing Worldwide Governance Indicators on an annual basis since 1996 distinguishing six dimensions of governance: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law and control of corruption all of which are "useful for broad cross-country and over-time comparisons of governance"(Kaufmann et al. 2009). These indicators show for example a significant decline comparing voice and accountability and political stability of 1998 and 2008 in Thailand, whereas most of the Eastern European States show a positive development. That means positive and negative trends in governance at state level can be measured and assess. The Index shows for example for the dimension “Political Stability/ Absence of Violence” that the trends in Nepal, Pakistan, Zimbabwe, Philipines and Nigeria are rather showing an increase in problems linked to political stability and violence, while in countries such as Angola, South Africa and Armenia these trends have taken a more positive development towards an improved level of political stability and absence of violence. However, it has also to be noted that the absolute values are important for the interpretation, that means countries which has a significant deficit in political stability in 1998 – such as Angola – increase their performance, however, they are still on a low level of political stability and still need to improve on problems related to violence (see Kaufmann et al. 2009., p. 33).

In some developed countries, the last 30 years have witnessed a shift in environmental governance practices towards more integrated approaches. For example EU environmental policy has transitioned from the use of remedial measures in the 1970s, to end of pipe pollution reduction strategies in the 1980s followed by integrated pollution prevention and control in the 1990s. With the turn of the century there has been recognition of the need to move beyond technical solutions and to deal with the patterns and drivers of unsustainable demand and consumption. This has resulted in the emergence of a more integrated approach to environmental management, a focus on prevention (UNEP, 2007), the incorporation of knowledge from the local to global in environment policies (Karlsson, 2007) and co-management and involvement of stakeholders from all sectors in the management of natural resources (McConnell, 2008; Plummer 2006) although some issues associated with the efficacy of this new paradigm have been identified (Armitage et al., 2007; Sandstrom, 2009).

In the specific areas of environmental health and water there are clear indications in some countries of a transition to more integrated, differentiated and collaborative approaches to environmental health risk and water resource management (Memon et al., 2010; Runhaar et al., 2010). As a response to changes in ecological systems there also appears to be evidence for the development of new governance structures for tackling global pandemic diseases, the management of marine resources and the possible advent of migration related to environmental changes (Duit et al., 2010) as well as a the recognition that socio-ecological changes require long-term policy solutions, are embedded in complex systems and require more than single best effort solutions because they are linked to a wide range of human activities (Underdal, 2010). Despite the potential for such trends in governance to moderate environmental risk, empirical analyses and evaluations of the impacts of environmental governance changes on bringing about historical changes in exposure and vulnerability to extreme climate events is scarce, although there are local highly specific success stories (see Section 2.4). This may well be due to the time lag between policy implementation and effect which often extends beyond one human generation (Underdal, 2010).

2.7.7. Influence of Gradual Climate Change

There is high confidence that climate change will affect disaster risk not only through changes in the frequency, intensity and duration of some extreme events (see chapter 3), but also through indirect effects on vulnerability and exposure. In most cases, it will do so not in isolation but as one of many sources of possible stress, for instance through impacts on the number of people in poverty or suffering from food and water insecurity, changing disease patterns and general health levels and where people live. In some cases, these changes may be positive, but in many cases, they will be negative, especially for many groups and areas that are already among the most vulnerable. While there is high confidence that these connections exist, current knowledge does not allow us to provide specific quantifications.

Table 2-7 identifies several observed and projected climate change impacts identified in the Fourth Assessment Report (AR4) (IPCC, 2007) that affect vulnerability and exposure. Given the highly differential nature of vulnerability and exposure, these effects will be different from place to place and person to person. However, as pointed out in the AR4, the most vulnerable groups are likely to be affected the worst by these changes, and consequently suffer the largest increases in exposure and vulnerability to extreme events.

[INSERT TABLE 2-7 HERE:
Table 2-7: Examples of observed and projected climate change impacts identified in the Fourth Assessment Report (AR4) (IPCC, 2007) that affect vulnerability and exposure.]

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.

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

- Risk identification (involving individual perception, social interpretation, and evaluation of risk)
- Risk reduction (which involves prevention and mitigation –of hazard or 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).

For all interventions, these should be followed by a final assessment step of continuous evaluation of actions taken to manage the risks.

The first three actions are mainly *ex ante*; i.e. they take place in advance of disaster, and the fourth refers mainly to *ex post* actions, although preparedness and early warning do require *ex-ante* planning. 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; 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 more risk-aware behavior and decisions 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.
- Knowledge of adaptive capacity status and limitations

(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 2005; and Kasperson *et al*. 2005)

In addition, in order to arrive at appropriate risk governance, especially in context of changing risks, effective communication about risk is essential (van Sluis and van Aalst 2006; ICSU-LAC 2010). 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.

2.8.2. Vulnerability and Risk Assessment

Risk analysis was an issue of interest in Babylonian times already. 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 (as discussed in Box 2-6) (see IDEA, 2005; Cardona, 2006; Birkmann, 2006a; Wisner, 2006a; IFRC, 2008; Dilley, 2006; and Peduzzi *et al.,* 2009).

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Box 2-6. Community-Based Participatory Climate Risk Assessment

Risk assessment at the local level presents specific challenges related to a lack of data (including climate data at sufficient resolution, but also socio-economic data at the lowest levels of aggregation) but also the highly complex and dynamic interplay between the capacities of the communities (and the way they are distributed among community members, including their power relationships) and the challenges they face (including both persistent and acute aspects of vulnerability).

Local people often have a much more sophisticated insight into many of these determinants of risk than outsiders, even when those outsiders have access to much more advanced modelling tools that allow deeper insight into the hazards facing the location. For effective risk management, risk assessment must be locally-based and lead to not only understanding but also a sense of local ownership of the diagnosis and the options that may be employed to address the risks. Several participatory risk assessment methods, often based on participatory rural appraisal methods, have been adjusted to explicitly address changing risks in a changing climate. Examples of such guidance on how to assess climate vulnerability at the community level include Willows and Connell, 2003; Moench and Dixit, 2007; Van Aalst *et al.,* 2007; CARE, 2009; IISD *et al*., 2009; Tearfund, 2009. In integrating climate change, a balance needs to be struck between the desire for a sophisticated assessment that includes high-quality scientific inputs as well as rigorous analysis of the participatory findings, and the need to keep the process simple, participatory and implementable at scale.

For more details on the implementation of risk management at the local level, see chapter 5.

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In general terms, according to the International Standards Organization risk assessment can be defined as a process to comprehend the nature of risk and to determine the level of risk (ISO, 2009a/b). 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., 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 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.

Usually risk has been associated to probabilities, but in general taking into account epistemic and aleatory uncertainties the *probabilistic estimations* of risk attempt to forcast damage or losses even where insufficient data are available on the hazards and 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 risk assessment based on probability, 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; Spence and Coburn 1987;Coburn and Spence, 1992; Woo, 1999; Grossi and Kunreuther, 2005; Cardona *et al.,* 2008a/b; Cardona 2010a).

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 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.,* 2003b).

The risk estimate must be prospective, anticipating scientifically possible hazard events that may occur in the future. For instance, for the case of hurricane-winds, the hydrometeorologic information available of the historic or future hurricanes –using climate change models or simulations– that have or may affected the area of study is used and, jointly with engineering methodologies, the effects of these phenomena upon the exposed current or future 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 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. Note that each of these factors may be subject to change in a changing climate (including consideration of uncertainty ranges).

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. The usefulness of indicators depends on how they are employed (Cardona et al., 2003; IDEA 2005; Cardona, 2006). The way in which indicators are used to produce a diagnosis has at least two implications: The first is related to the structuring of the theoretical model. The second relates to the way risk management objectives and goals are decided on. These aspects are relevant 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 alternatives, information on which is critical to organize and orientate the praxis of effective intervention (IDEA 2005). An appropriate technique based on indicators or composite indices can be a rational benchmark or a common metric to rule the risk variables from a control point of view; the goal in this case is not to reveal the truth, but rather to provide information and analyses that can improve decisions (Cardona, 2005; Carreño *et al.,* 2007b, 2009). Box 2-7 illustrates how with a particular indicator it is possible to communicate disaster risk to country's financial authorities in their own financial language.

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Box 2-7. The Disaster Deficit Index: A Metric for Sovereign Fiscal Vulnerability Assessment

Future disasters have been identified as contingency liabilities and could 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. 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, 2010b; 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. Figure 2-4 shows the DDI for 2008.

[INSERT FIGURE 2-4 HERE:
Figure 2-4: Disaster Deficit Index (DDI) and Probable Maximum Loss in 500 Years for 19 countries of the Americas for 2008. Source: Cardona, 2010b]

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. [add discussion on applications]

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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 or adaptation decision-making. Results can be verified and risk management/adaptation priorities can be established (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 and Birkmann (2004) and Cardona, (2001). 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. Similar frameworks have been developed from an adaptation perspective (insert refs).

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 specific options (technical and structural as well as non-technical and non-structural) on how to reduce vulnerability and risk levels, which can then be appraised against identified criteria. (Cardona, 1999; Cardona and Hurtado, 2000a/b; Cardona and Barbat, 2000; Turner *et al.,* 2003; IDEA 2005; Birkmann, 2006b; Carreño *et al.,* 2005, 2007a, 2009; ICSU-LAC 2010). Figure 2-1 contours a holistic and integrative perspective.

Several methods have been proposed to measure vulnerability from a comprehensive and multidisciplinary perspective. In some cases composite indices or indicators intend to capture favourable conditions for direct physical impacts –such as exposure and susceptibility– as well as indirect or intangible impacts of hazard events –such as socio-ecological fragilities or lack of resilience– (IDEA, 2005; Cardona, 2006; Carreño *et al.,* 2007a). In these holistic approaches, exposure and physical susceptibility are representing the ‘hard’ and hazard dependent conditions of vulnerability. On the other hand, the propensity to suffer negative impacts as a result of the socio-ecological fragilities and not being able to adequately cope and anticipate disasters, can be considered ‘soft’ and usually non-hazard dependent conditions, that aggravate the impact. Box 2-8 describes one of these approaches based on relative indicators useful for monitoring vulnerability of countries over time.

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Box 2-8. 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, 2010b; IDEA, 2005) provides a holistic approach to relative vulnerability assessment using social, economic and environmental indicators. The PVI depicts predominant vulnerability conditions of the countries over time to identify progresses and regressions. 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 demographic, socio-economic, and environmental national indicators that reflect situations, causes, susceptibilities, weaknesses or relative absences of development affecting the country under study. The indicators are selected based on existing indices, figures or rates available from reliable worldwide databases or data provided by each country. These vulnerability conditions underscore the relationship between risk and development. Figure 2-6 shows the aggregated PVI (Exposure, Social Fragility, Lack of Resilience) for 2007 and for the last four periods.

[INSERT FIGURE 2-5 HERE:
Figure 2-5: Aggregate Prevalent Vulnerability Index (PVI) for 19 countries of the Americas for 2007. Source: Cardona, 2010b]

Vulnerability and therefore risk are the result of inadequate economic growth and deficiencies that may be corrected by means of adequate development processes, reducing susceptibility of exposed assets, socio-economic fragilities, and improving capacities and resilience of society (IDB, 2007). 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. The PVI can be used at different territorial levels, however often the indicators used by the PVI are only available at national level; this is a limitation for its application in other subnational scales.

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To enhance disaster risk management and climate change adaptation, besides strengthening the integrative and holistic perspective within risk and vulnerability assessment, risk identification and vulnerability assessment has to be undertaken in different phases, i.e. before, during and even after disasters occur. Particular attention should be given to the evaluation of the continued viability of measures taken and/or identifying the need for further or different adaptation/risk management measures. 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, 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 main 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 (Corral, 2000). Applicability is related 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 method or algorithm. Presentation refers to the transformation of the information, visualization, and understanding of the outcomes. Finally, legitimacy is linked to the role of the analyst, control, comparison, the possibility of validation, and acceptance and consensus of the evaluators and decision-makers (Cardona, 2003b; Cardona, 2010a).

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Box 2-9. Climate Risk Assessment and Screening for Development Projects and Portfolios

A specific area of risk screening for risks related to climate change relates to development projects financed by international donor agencies and development banks, and their overall portfolios of development projects and loans. As part of their standard operations, they have traditionally assessed the risk that their projects could pose to the environment, specifically using instruments such as environmental impact assessments. In light of climate change, these questions have expanded to include (a) the risk that climate change could pose to the project itself (for instance in the case of infrastructure collapse); (b) the risk that climate change could pose to the project's intended outcomes (for instance when investments would not pay off as expected); (c) the risk that the project could generate to the vulnerability of its surroundings (for instance when a project generates employment in an unsuitable area so that it increases exposure to future hazards). Initial risk assessment for such risks has a dual role of technical screening and awareness raising of project managers of potential issues to be addressed. It is often accomplished through a very simple set of questions. Follow-up risk assessment would be much more in-depth and conducted by expert consultants. At portfolio level,

Given their focus on the near future (planning horizons of most development projects are typically up to about 20 years, even if the physical lifetime of the investment may be much longer) and need to combine attention for current and future risks, several of these risk assessment methods for development agencies have paid specific attention to the risk of variability and extremes, and thus offer significant win-wins between adaptation to climate change and enhanced disaster risk management even in light of current hazards (see e.g. Van Aalst and Burton, 1999, 2004; Klein, 2001; Klein *et al.,* 2007; Agrawala and van Aalst, 2008; and Tanner, 2009).

For more details on the implementation of risk management at the national level, see chapter 6.

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2.8.3. Risk Communication

Risk assessments and risk identification have to be linked to different types and strategies of risk communication. Risk communication or the failure of effective and people centred risk communication is often contributing to an increasing vulnerability and disaster risk. Knowledge on factors that determine how people perceive and respond to a specific risk or a set of multi-hazard risks is key for risk management and climate change adaptation (see van Aalst et al. 2008; Grothmann/Patt 2005).

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, 2005; Birkmann, 2006a/b/c; Cutter/Finch 2008 and ICSU-LAC, 2010). In this regard, risk communication is not solely linked to a top-down communication process, rather effective risk communication requires that communication is a dialog meaning that risk communication also deals with local risk perceptions and local definitions of risk. Risk communication thus functions also as a tool to up-scale local knowledge and needs (bottom-up approach). Therefore, modern risk communication is about both an improved way to inform people at risk about the key determinants of risk or acute disaster risk (early warning), but also a way on how to engage different stakeholders in the definition of a problem and the identification of respective solutions (see van Aalst et al. 2008, p. 177; DKKV et al. 2010 [note: title: emerging challenges for early warning systems in the context of climate change and urbanization (study)].

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 identify and evaluate 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. The failure of risk communication has been revealed in past disasters, such as Hurricane Katrina in 2005 or the Pakistan Floods in 2010. Particularly, the loss of trust in official institutions, responsible for early warning and disaster management were a key factor that contributed to the increasing disaster risk. Effective and people centred risk communication is therefore a key to improve vulnerability and risk reduction. In contrast, weak and insufficient risk communication as well as the loss of trust in governmental institutions in the context of early warning or climate change adaptation can be seen as a core component of institutional vulnerability.

Climate change adaptation strategies as well as disaster risk reduction approaches need public interest and acceptance. In this context the role of mass media becomes increasingly important (see e.g. the case of Japan shown in Sampei/Aoyagi-Usui 2009). Communication within society is more and more organized according to the rules of the mass media. Mass media do not reflect or echo reality. However modern society take notice of climate change and disasters as they are communicated by professional media (Rhomberg 2009). Within the context of risk communication, particularly in terms of climate change and disasters, politicians, scientists and NGOs have to observe the logics of the media concerning news production public discourse and media consumption (see Carvalho and Burgess 2005). Knowing the rules and routines of the media is a prerequisite to develop strategies to find attention and support (Anderson 2009). Disasters, people affected and harm is often taken up by the mass media worldwide, however, it is difficult to communicate a differentiated picture about underlying vulnerabilities, mechanisms of climate change and particularly the uncertainties related to climate change (see Smith 2007). Additionally, Carvalho (2005) and Olausson (2009) underline that mass media is often closely linked to political awareness, that means also that mass media does solely provide little space for alternative frames of communicating climate change (Carvalho 2005, Olausson 2009). Furthermore, risk communication in the context of mass media has to acknowledge that the presentation of climate change is not only determined by the routines of mass media, but rather also by the different interest groups (see e. g. Dispensa and Brulle 2003). In this regard Boykoff and Boykoff (2007) conclude that this process might also leads to an informational bias, especially towards the presentation of sudden-onset hazards. In contrast climate change related risks are often related to future risks and risk modifications that are based on scenarios about the future, thus communication about possible effects of climate change inevitably involves uncertainty (see e.g. Morton et al. 2010). Thus, an important aspect of improving risk communication and the respective knowledge base is the acceptance and admission of the limits of knowledge (see Birkmann/Teichman 2010, p. 181). Additionally, it is essential to underline within risk communication strategies that disasters are determined not solely by one event or trigger, but by various developments that often run in parallel and that at a certain point in time reach (in their combination) a threshold that might lead to a disaster (see Dikau/Pohl 2007).

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.

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Box 2-10. Lessons on Risk Perception and Communication from Early Warning Systems

[TBD – coordinate with chapter 9]

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2.9. Risk Accumulation and the Nature of Disasters

2.9.1. Risk Accumulation

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. It also reflects that the impacts of one hazard – and the response to it – can have implications for how the next hazard plays out. This is well illustrated by the example of El Salvador, where people living in temporary shelters after 1998 Hurricane Mitch were at greater risk during the 2001 earthquakes, due to the poor construction of the shelters (Wisner, 2001). The notion is important because it acknowledges the multiple causal factors of risk by implying the connection between development patterns and risk, as well as the links between one disaster and the next. In many ways, this notion, which stems from the disaster risk reduction community, embodies why climate change poses such a threat to humanity and ecosystems.

Risk accumulation can be driven by underlying factors such as 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 (Pelling and Satterthwaite, 2007). 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). Similar accumulation of risk may occur at larger scales in hazard-prone states, especially in context of conflict and displacement (e.g. UNDP, 2004).

A context-based understanding of these risks is essential to identify appropriate risk management strategies. 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 one of the most effective methods to address urban disaster risk in Africa is to support community processes amongst the most vulnerable groups so they can 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 that rapidly go out of date due to unplanned construction.

2.9.2. The Nature of Disasters and Barriers to Overcome

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; research-based knowledge must be considered relevant, true, unbiased, and applicable in order to have impact on decision makers in policy and practice (Mitchell et al. 2006, Weichselgartner and Kasperson 2010). Effective risk management also requires a good understanding of the underlying vulnerability, as well as effective communication and dissemination of risk knowledge. Also an enabling environment to provide those in need with access to means of protection. 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. 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 it is important highlight 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).

This chapter highlights how risk is determined not just by hazards, but importantly also by vulnerability and exposure. To address risk at its core therefore, rather than just superficially, transformative changes in development patterns are necessary. 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. However, there is often also strong pressure to restore the status quo as soon as possible after a disaster has happened, and unless proper risk assessment and reconstruction planning has been carried out even before a particular disaster occurs, the benefits of better analysis and more appropriate solutions have to be weighed against the cost of delays in restoring essential assets and services.

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 system 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 in some cases 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.

That then also leads to the research gap of how to inform robust decisions and improve the decision making process where uncertainties are high, including improved methods for identification, appraisal, monitoring and evaluation of flexible and incremental options.

A related 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 stakeholder engagement. An additional gap relates to the characterization and measurement of (adaptive) capacities, including implications for policy and practice in specific sectors and at various scales.

At the local level, a methodological gap is the development and application of appropriate climate risk assessment methodologies 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 related interest is improved characterization and quantification of various indirect feedbacks between climate change and disaster risk, e.g. 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 and/or to future gradual climate change, including through human systems and ecosystems, as well as how various policy options may affect these interactions (positively and/or negatively).

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

Dimensions	Characteristics	Sources
Multiple and Intersecting	(a) Social capital and the importance for climate change adaptation of acting collectively particularly in resource-dependent communities; (b) Although most often referred to as desirable, there are positive and negative benefits/distributional effects of social capital;	(a) Adger 2003 Social Capital, Collective Action, and Adaptation to Climate Change (b i) Aldrich, D. P., 2011: The Externalities of Strong Social Capital: Post-Tsunami Recovery in Southeast India. Forthcoming in Journal of Civil Society April 2011. Electronic copy available at: http://ssrn.com/abstract=1719642; (b ii) World Disasters Report 2007 - Focus on discrimination Accessed 20 January 2011 http://www.ifrc.org/Docs/pubs/disasters/wdr2007/WDR2007-English.pdf ; (b (b iii) Ibarraran, M. E., Ruth, M., Ahmad, S. and London, M., 2009 Climate change and natural disasters: macroeconomic performance and distributional impacts, Environ Dev Sustain (2009) 11:549–569

Gender	a) Unequal gender relations arising from patriarchal structures can create new vulnerabilities or worsen existing ones for women and girls in disasters. b) Men and women have different entitlements/access to resources and abilities to reduce their vulnerability through various coping and adaption practices c) Men may be more mobile and have more opportunities to use large blocks of time on a single pursuit (e.g. livelihood activities) while women generally cannot because of their range of reproductive duties and thus are disadvantaged in post-disaster recovery d) Women are a heterogeneous group and cannot be assumed to be equally vulnerable, everywhere and all of the time e) Gender is a cross cutting issue which can qualify all vulnerability dimensions. f) Gender should be understood as an inclusive term and not simply a binary (male, female) one. Groups defined/self-defining as transgender or non heterosexual are particularly invisible and under-researched; their marginalization leads to discriminatory practices in extreme events g) Increasing amounts of research have identified post-disaster violence against women	(a i) Enarson E. and Morrow, B. H. 1998 (a ii) Neumayer and Plümper 2007 (b i) Sen 1982 (c i) Eriksen, Brown and Kelly, 2005: 300-301 (d i) Fordham, 1999 (d ii) Enarson and Fordham, 2001; (d iii) Peacock *et al.* 1997; (d iv) Fothergill, 1996 (e i) ISDR Words Into Action (f i) Pincha C. and Krishna, N. H. 2009 Post-disaster death ex gratia payments and their gendered impact" Regional Development Dialogue (UNCRD) 30 (1) pp 95-105; (g i) Enarson, E. 1999 Violence Against Women in Disasters: A Study of Domestic Violence Programs in the United States and Canada, *Violence Against Women*, 5: 742-768; (g ii) Houghton Ros 2009 "Domestic Violence reporting and disasters in New Zealand" Regional Development Dialogue Vol 30 (1) pp 79-90

Age	In terms of age, it is often those at the extreme ends of the age range who are identified as vulnerable in disasters. (a) Children 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 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 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. (b) elderly people have been identified as at greater risk in heatwaves	(a i) Jabry, 2002; (a ii) Wisner, 2006b). (a iii) Bartlett, C., 2008: Climate change and urban children: impacts and implications for adaptation in low- and middle income countries *Environment & Urbanization* Vol 20(2): 501–519 (b) see Heat Wave Case Study
Race/ Ethnicity/ Religious Associations (link to culture)	a) Racial and ethnic inequities in several US disasters b) Evidence of differential access to relief	(a i) Fothergill, A., Maestas, E.G.M. and Darlington, J-Anne de R. 1999 "Race, Ethnicity and Disasters in the United States: A Review of the Literature" Disasters, 23(2):156-173; (a ii) Elliott, J. R. And Pais, J. 2006 "Race, class, and Hurricane Katrina: Social differences in human responses to disaster" Social Science Research 35 (2006) 295–321; (a iii) Cutter and Finch, 2008.
Dis/Ability	People with disabilities may be vulnerable in disasters because of their impairments and because they are more likely to be living in poverty, and they may be institutionalised and dependent on others. They are generally marginalized from disaster risk reduction planning or adaptation mechanisms. Disasters also create disabilities.	World Disasters Report 2007 - Focus on discrimination Accessed 20 January 2011 http://www.ifrc.org/Docs/pubs/disasters/wdr2007/WDR2007-English.pdf
Wealth/ Poverty	a) Vulnerability is not equal to poverty; it is context specific. However,	a) Blaikie *et al.*, 1994
Class/ Caste	a) Guatemalan earthquake of 1976 termed a 'classquake'	a) O'Keefe *et al.,* 1976

Table 2-3: *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 desertification, 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.

Table 2-4 *Examples of generated sensitivity and adaptive capacity indices for agriculture and fisheries in Sri Lanka*

Sensitivity index	**Adaptive capacity index**
For drought and flood	**For drought and flood**
Area of paddy cultivation	• Percentage of people employed in agriculture with education below O/L • Percentage of landless paddy farmers • Percentage agriculture share in income (among those employed in agriculture) • Percentage of paddy land not fed by major irrigation
For sea level rise	**For sea level rise**
Area of paddy cultivation within 5km from the coast line	• Percentage of people employed in agriculture with education below O/L • Percentage of landless paddy farmers • Percentage agriculture share in income (among those employed in agriculture) • Percentage of paddy land not fed by major irrigation

Table 2-5: *Possible Health Threats from Climate Change*

Climate Change Threat	Potential Health Impacts
Heat waves	• Direct deaths (heat stroke; dehydration) • Exacerbation of chronic cardiovascular and pulmonary conditions
Air pollution	• Increased concentration of ground-level ozone. • Exacerbation of chronic cardiovascular and pulmonary diseases
Flooding (coastal and other)	• Contamination of potable water • Increased exposure to disease and pollutants • Indoor mold and respiratory illness • Deaths (drowning and indirect causes) • Forced evacuation and relocation • Mental health problems
Deterioration of food and water supply	• Increase in food poisoning (salmonellosis) • Increase in water-borne diseases (cryptosporidiosis)
Vector-borne diseases	• Expansion of habitat for mosquitoes •Geographic shifts in malaria, other insect borne diseases
Increased sunlight (more outdoor activity)	• Skin cancer • Increased rate of eye cataracts
Drought	• Water shortages • Contamination of water supplies • Reduced personal and community hygiene
Deterioration of long-standing agricultural areas	• Impaired crop yields • Food shortages • Greater use of pesticides and fertilizers • Shifts in diet
Hurricane, typhoons and extreme storm frequency and severity	• Storm-related deaths • Major property damage and insurance losses • Mental health problems

Table 2-6: *Examples of vulnerability indicators for freshwater resources (Source: 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

Table 2-7 *Examples of observed and projected climate change impacts identified in the Fourth Assessment Report (AR4) (IPCC, 2007) that affect vulnerability and exposure.*

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/

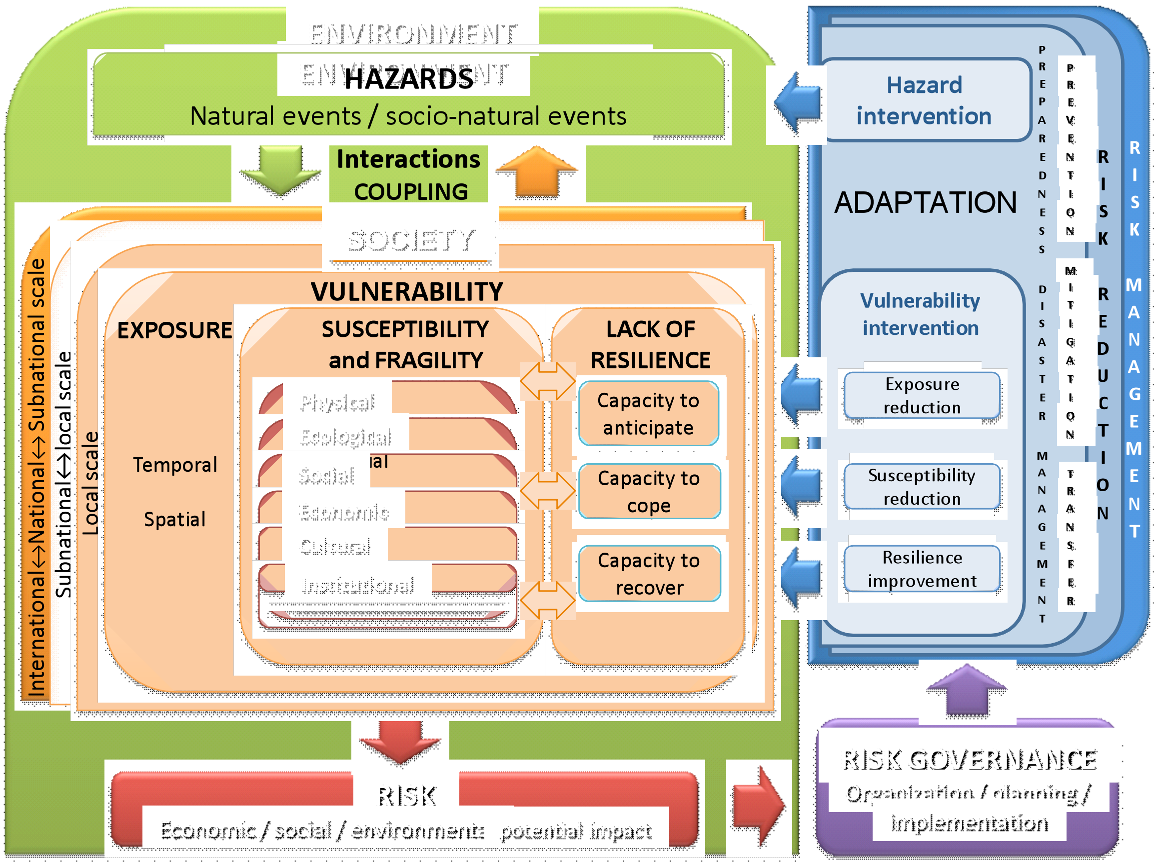

Figure 2-1: MOVE project framework on vulnerability and disaster risk assessment and management. Source: MOVE (2010).

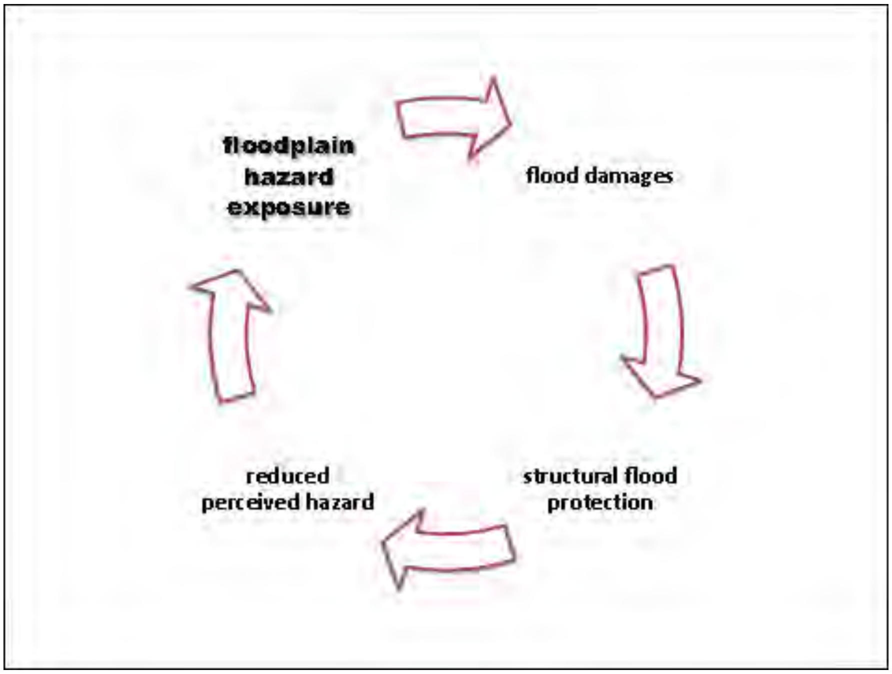

Figure 2-2. Reactive and maladaptive policy responses: the 'levee effect' in floodplain hazard exposure.

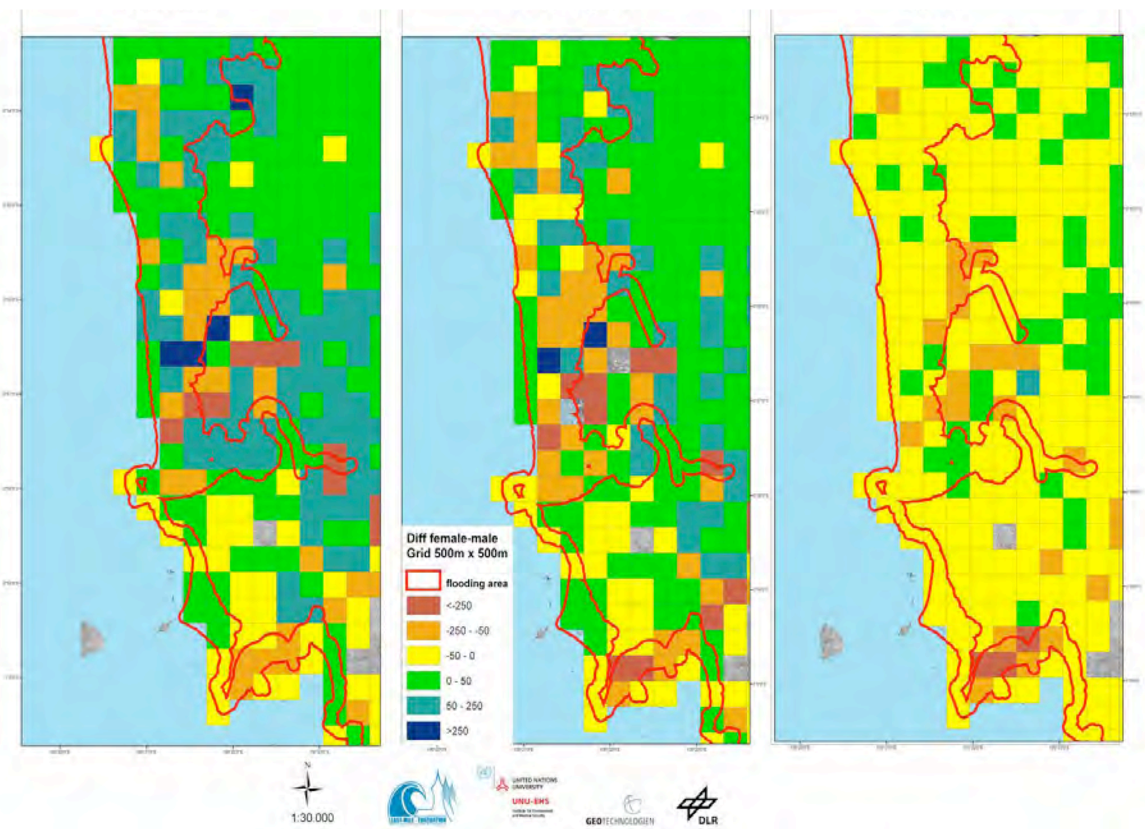

Figure 2-3: Difference between female-male population during morning, afternoon and night, for the coastal city of Padang, demonstrating differential exposure of women over time of day in the high risk zone close to the sea (Setiadi et al., 2010).

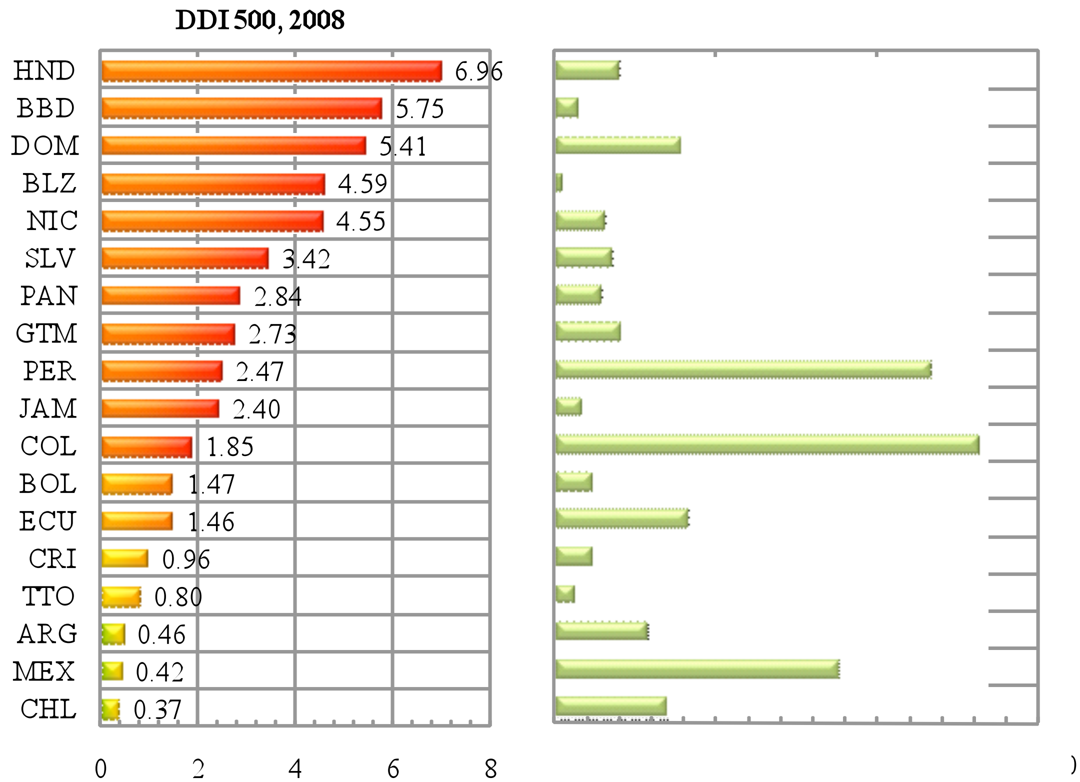

Figure 2-4: *Disaster Deficit Index (DDI) and Probable Maximum Loss in 500 Years for 18 countries of the Americas for 2008. Source: Cardona, 2010b*]

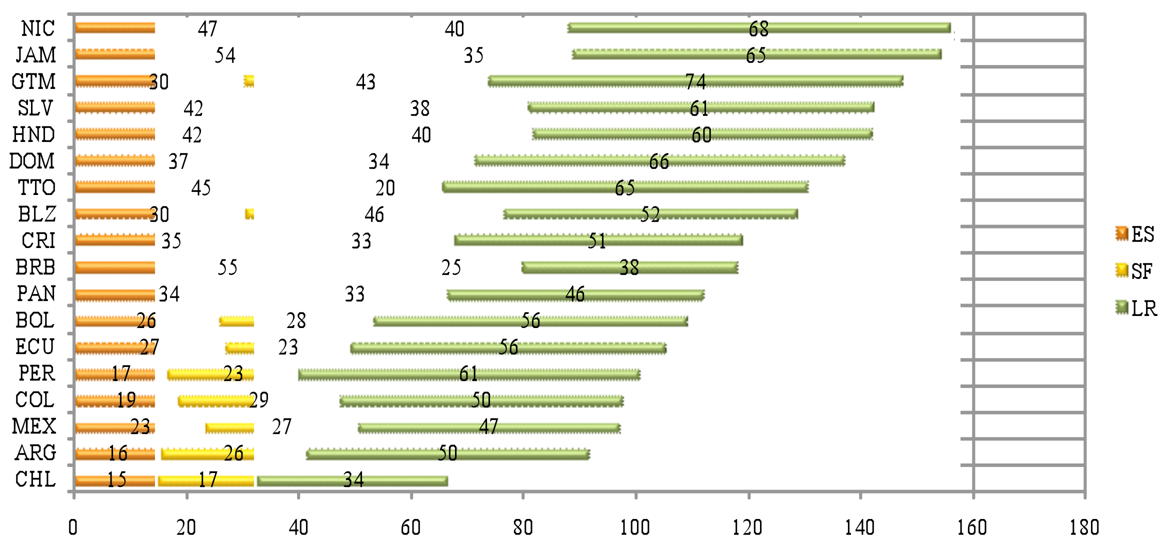

Figure 2-5: *Aggregate Prevalent Vulnerability Index (PVI) for 18 countries of the Americas for 2007. Source: Cardona, 2010b.*
Components of the PVI: ES: exposure and susceptibility; SF: socioeconomic fragilities; LR: lack of resilience

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

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Executive Summary

A changing climate can lead to changes in the frequency, intensity or duration of an extreme event, or result in an unprecedented, previously unobserved, extreme. As well, a weather or climate event, although not necessarily extreme in a statistical sense, still may have an extreme impact, either by crossing a critical threshold in a social, ecological or physical system, or because it occurs simultaneously with another event combined with which it leads to extreme conditions or impact. Conversely, not all extremes necessarily lead to serious impacts. Meteorological phenomena such as a tropical cyclone can have an extreme impact, depending on where and when it makes landfall, even if the specific cyclone is not extreme relative to other tropical cyclones. Changes in phenomena such as El Niño – Southern Oscillation or monsoons may affect the frequency and intensity of extremes in several regions simultaneously. [3.1]

Many weather and climate extremes are the result of natural climate variability (including phenomena such as El Niño), and natural decadal or multi-decadal variations in the climate provide the backdrop for possible anthropogenic changes. Even if there were no anthropogenic changes in climate over the next century, we can still anticipate a wide variety of natural weather and climate extremes to occur. Changes in extremes of a climate or weather variable are not always related in a simple way to changes in the mean of the same variable, and in some cases can be of opposite sign to a change in the mean of the variable (e.g., precipitation intensity may increase in some areas and seasons even if the total precipitation decreases). [3.1]

There is evidence of some changes in extremes occurring over recent decades (i.e., since 1950). It is *very likely* that there has been an overall decrease in the number of unusually cold days and nights, and an overall increase in the number of unusually warm days and nights, on the global scale, i.e., for land areas with data It is *likely* that this statement also applies at the continental scale in North America and Europe, and *very likely* that it applies in Australia. There is *medium confidence* of a warming trend in temperature extremes in Asia. There is *low confidence* in observed trends in temperature extremes in Africa and South America. It is *likely* that the number of warm spells, including heatwaves, have increased since the middle of the 20th century in many (but not all) regions. It is *likely* that there has been statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than there has been statistically significant decreases, but there are strong regional and subregional variations in the trends. There is *low confidence* that any reported long-term increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities. There is *medium confidence* that since the 1950s some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but also opposite trends exist e.g., in Central North America and Northwestern Australia. [3.3.1; 3.3.2; 3.4.4; 3.5.1; Table 3.2]

Our confidence in projecting changes (including the direction and magnitude in extremes) varies with the type of extreme, as well as the considered region and season, linked with the amount and quality of relevant observational data, the level of understanding of the underlying processes, and the reliability of their simulation in models. *Low confidence* in projections of a specific extreme neither implies nor excludes the possibility of changes in this extreme. [3.2.3; 3.1.5]

The following assessments of the likelihood and/or confidence of projections are generally for the end of 21st century. The reference climate period is generally 1961-1990. Projections for differing emissions scenarios generally do not strongly diverge in the coming two to three decades, but uncertainty is large over this time frame due to natural climate variability. For certain extremes (e.g., precipitation-related extremes), the overall uncertainty in projected changes by the end of the 21st century is more strongly influenced by model uncertainty than by uncertainty associated with emissions scenarios. For other extremes (in particular temperature extremes on the global scale and in most regions), the scenario uncertainty is the dominant source of uncertainty by the end of the 21st century. The provided assessments modify the uncertainty ranges from the direct evaluation of multi-model ensemble projections by taking into account the past performance of models in simulating extremes, the possibility that some important processes relevant to extremes may be missing or be poorly represented in models, and the limited number of model projections and corresponding analyses currently available of extremes. For these reasons the assessed uncertainty is generally less confident than would be the uncertainty range from the model projections alone. [3.2.3, 3.3.1, 3.3.2, Box 3.1]

Model projections of changes in temperature extremes are for substantial warming by the end of the 21st century. However, simulations of late 20th century changes in extreme temperatures suggest that although models simulate temperature extremes quite well, they may over-estimate the warming. The following assessments take this possible over-estimation into account, along with the possibility that some processes important for temperature extremes may be missing or be poorly represented in models. It is *virtually certain* that the observed increases in the warm extremes of daily temperature and decreases in their cold extremes, will continue into the future on the global scale and in most regions. It is *very likely* that the length, frequency and/or intensity of heatwaves will continue to increase over most land areas. For the SRES A2 and A1B emission scenarios, a one-in-20 year annual hottest day is *likely* to become a one-in-

two year annual extreme by the end of the 21st century in most regions, except in the high latitudes of the northern hemisphere where it is *likely* to become a one-in-five year annual extreme. Moderate (cold and warm) temperature extremes on land are projected to warm faster than global annual mean temperature in many regions and seasons. A mean global warming of 2°C or 3°C is *likely* to lead to much larger increases in some temperature extremes in certain regions and seasons (with scaling factors for the SRES A2 scenario *likely* ranging between 0.5 and 2.5 for moderate seasonal extremes). Nevertheless, mean global warming does not necessarily imply warming in all regions and seasons. [3.3.1; 3.1.6; Table 3.3]

It is *likely* that the frequency of heavy precipitation (or proportion of total rainfall from heavy falls) will increase in the 21st century over many areas of the globe, in particular in the high latitudes and tropical regions, and in winter in the northern mid-latitudes. Some studies also suggest increases in heavy precipitation in some regions with projected decreases of total precipitation, such as Central Europe (*medium confidence*). For a range of emission scenarios (SRES B1/A1B/A2), a one-in-20 year annual maximum 24-hour precipitation rate is *likely* to become a one in 5- to 15-year event by the end of 21st century in many regions, and in most regions the more extreme emissions scenarios (A1B and A2) lead to a stronger projected decrease in waiting time. Nevertheless, increases or statistically non-significant changes in waiting times are projected in some regions. [3.3.2; Table 3.3]

It is *very likely* that mean sea level rise will contribute to upward trends in extreme sea levels in the future. A relatively small change in mean sea level can result in a large change in extreme sea level, in some locations. There is evidence for projected increases in wave height in some regions such as the eastern North Sea, but the small number of studies, the lack of consistency of the wind projections between models, combined with limitations in their ability to simulate extreme winds, means there is *low confidence* in these. Future negative or positive changes to significant wave height are *likely* to reflect future changes in storminess and associated patterns of wind change. There is *high confidence* that locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future due to increasing sea levels all other contributing factors being equal. [3.5.3; 3.5.4; 3.5.5]

The magnitude and even the sign of any anthropogenic influence on global patterns of floods are uncertain, and causes of regional changes in floods are complex; thus there is *low confidence* (due to *limited evidence* as well as to *low agreement of projections)* in projections of changes in flood magnitude and frequency. Nevertheless, an increase in the magnitude and/or frequency of rain-generated floods is anticipated in some catchments and regions where short-term (e.g., daily) rainfall extremes and/or long-term (e.g., monthly, wet-season total) rainfall extremes are projected to increase. Earlier spring peak flows in snowmelt and glacier-fed rivers are *very likely*. [3.5.2]

There is at most *medium confidence* in the projected changes in drought characteristics, because of inconsistent projection*s* of the sign of changes in several regions (dependent both on model and dryness index choice). There is *medium confidence* that droughts will intensify in the 21st century in some seasons and areas (including the Mediterranean, Central Europe, Central North America, and South Africa), due to an enhanced precipitation deficit and/or evapotranspiration excess. Projections of drought intensification are stronger for the more extreme emissions scenarios (A2/A1B) than for more moderate scenarios (B1), but uncertainty between models is larger than that due to scenario choice. There is *low confidence* in projected future changes in dust activity. [3.5.1; 3.5.8; Table 3.3]

The relatively few studies of projected extreme winds, and shortcomings in the simulation of these events, mean that we have *low confidence* in projections of changes in strong winds. An exception is mean tropical cyclone maximum wind speed, which is *likely* to increase, although increases may not occur in all ocean basins. It is *likely* that tropical cyclone related rainfall rates would increase with continued warming induced by enhanced greenhouse gas concentrations, but it is *unlikely* that the global frequency of tropical cyclones would increase. A reduction in the number of mid-latitude storms averaged over each hemisphere due to future anthropogenic climate change is as *likely as not* and models show large regional changes in cyclone activity, but there is *low* confidence in the detailed geographical projections. Confidence in a projected poleward shift of mid-latitude storm tracks due to future anthropogenic forcings is *medium*. [3.3.3; 3.4.4; 3.4.5]

There is *low confidence* in projections of changes in monsoons (rainfall, circulation), even in the sign of the change, because there is little consensus in climate models regarding the sign of future change in the monsoons. Land use changes and aerosols from biomass burning appear to influence monsoons, but these effects are associated with large uncertainties. [3.4.1]

Models project a wide variety of changes in El Niño – Southern Oscillation variability and the frequency of El Niño episodes as a consequence of increased greenhouse gas concentrations, and so there is *low confidence* in projections of changes in the phenomenon. However, most models project an increase in the relative frequency of central equatorial Pacific events (which typically exhibit different patterns of climate variations than do the classical East Pacific events). [3.4.2]

There is *medium confidence* that the number of shallow landslides and debris flows from recently deglaciated terrain will increase because of higher availability of unconsolidated sediment. There is also *medium confidence* that high-mountain debris flows will begin earlier in the year because of earlier snow melt. There is *low confidence* in projected changes in the magnitude and frequency of shallow landslides in temperate and tropical regions, as these depend mainly on frequency and intensities of rainfall events and land use. It is *likely* that permafrost degradation will decrease the stability of rock slopes, though there is *low confidence* regarding future locations and times of large rock avalanches as these depend on multiple factors particularly local geological conditions. Due to *very likely* sea ice retreat, and permafrost degradation, the frequency and magnitude of the rate of Arctic coastal erosion is *likely* to increase. [3.5.6; 3.5.7]

This report identifies the most likely changes in extremes based on current knowledge. The possibility of the occurrence of low-probability high-impact scenarios associated with the crossing of poorly understood thresholds cannot be excluded given the transient and complex nature of the climate system. Non-linear feedbacks play an important role in either damping or enhancing extremes in several climate variables. [3.1.4; 3.1.7]

3.1. Weather and Climate Events Related to Disasters

3.1.1. Categories of Weather and Climate Events Discussed in this Chapter

In this chapter, we address changes in weather and climate events relevant to extreme impacts and disasters, grouped into the following categories:

- Weather and climate elements (temperature, precipitation, wind)
- Weather and climate phenomena influencing the occurrence of extreme events (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-related impacts, landslides, and sand and dust storms)

The distinction between these three categories is somewhat arbitrary, and the categories are also 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 Section 3.1.3).

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. This means that all occurrences of El Niño are relevant to extremes and not only extreme El Niño episodes. A change in the frequency or nature of El Niño episodes (or in their relationships with climate in specific regions) would affect extremes in many locations simultaneously. Similarly, changes in monsoon patterns could affect several countries simultaneously. This is especially important from an international disaster perspective because coping with disasters in several regions simultaneously may be challenging (see also Section 3.1.3).

The rest of this section provides background material on the characterization and definition of extreme events, the definition and analysis of compound events, the relevance of feedbacks for extremes, the approach used for the attribution of confidence and likelihood assessments in this chapter, and the possibility of "surprises" regarding future changes in extremes. Requirements and methods for analysing changes in climate extremes are addressed in Section 3.2. Assessments regarding changes in the climate elements, phenomena and impacts considered in this chapter are provided in Sections 3.3 to 3.5. Table 3.1 provides summaries of these assessments for changes on the global scale. Tables 3.2 and 3.3 provide more regional detail on observed and projected changes in temperature and precipitation extremes. Note that impacts on ecosystems (e.g., bushfires) and human systems (e.g., urban flooding) are addressed in Chapter 4.

3.1.2. Characteristics of Weather and Climate Events Relevant to Disasters

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 (Chapters 1 and 2). In this chapter, we focus on the assessment of changes in "extreme (climate or weather) events" (also referred to herein as "climate extremes", see below), which correspond to the "hazards" discussed in Chapter 1. Hence, the present chapter does not consider the dimensions of vulnerability or exposure, which are critical in determining the human and ecosystem impacts of climate extremes (Chapters 1, 2 and 4).

The IPCC SREX defines an "extreme (climate or weather) event" as follows (SREX glossary):
"An *extreme (weather or climate) event* is generally defined as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends ("tails") of the range of observed values of the variable. Definitions of thresholds vary, but values with less than a 5% or 1% or even lower chance of occurrence during a specified *reference* period (generally 1961-1990) are often used. Absolute thresholds (rather than these relative thresholds based on the range of observed values of a variable) can also be used to identify extreme events (e.g., specific critical temperatures for health impacts). What is called an extreme weather or climate event will vary from place to place in an absolute sense (e.g., a hot day in the tropics will be a different temperature than a hot day in mid-latitudes), and possibly in time given some adaptation from society. Extremes in some climate variables (e.g., drought or flood) may not necessarily be induced by extremes in meteorological variables (precipitation, temperature), but may be the result of an accumulation of moderate weather or climate events. Compound events (see IPCC SREX Section 3.1.3), i.e., two (even moderate) events occurring simultaneously, can lead to high impacts, even if the two single

events are not extreme per se (only their combination). Not all extreme weather and climate events necessarily have extreme impacts."

The distinction between extreme *weather* events and extreme *climate* events is not precise, but is related to their specific time scales: An extreme weather event is typically associated with changing weather patterns, i.e., within time frames of less than two weeks. An extreme climate event happens on longer time scales, i.e., from several weeks to several years or even decades. It may also be the sum of several (moderate) extreme weather events (e.g., the accumulation of above-average rainy days over a season). For simplicity, we collectively refer to both extreme weather events and extreme climate events with the term "climate extremes" in this chapter.

From the above definition, it can be seen that climate extremes can be quantitatively defined in two ways:

- Related to their probability of occurrence
- Related to a specific (possibly impact-related) threshold

The first type of definition can either be expressed with respect to given percentiles of the probability distribution functions (pdf) of the variables, or with respect to specific return frequencies (e.g., "100-year event"). Compound events can be seen as a special category of climate extremes, which result from the combination of two or more events, and which are again "extreme" either from a statistical perspective (low probability of occurrence) or associated with a specific threshold (Section 3.1.3.). These two definitions of climate extremes, probability-based or threshold-based, are not necessarily antithetic. Indeed, hazards for society and ecosystems are often extreme both from a probability and threshold perspective (e.g., a 40°C threshold for midday temperature in the mid-latitudes).

A large amount of the available scientific literature on climate extremes is based on the use of so-called "extreme indices", which can either be based on the probability of occurrence of given quantities or on threshold exceedances. Typical indices that are seen in the scientific literature include the number, percentage or fraction of cold/warm days/nights (days with maximum temperature, Tmax or minimum temperature, Tmin, below or above the 10th percentile, or the 90th percentile, generally defined with respect to the 1961-1990 reference time period). Other definitions relate to e.g., the number of days above specific absolute temperature or precipitation thresholds, or more complex definitions related to the length or persistence of climate extremes (see also below). Some advantages of using predefined extreme indices are that they allow some comparability across modelling and observational studies and across regions (although with limitations noted below). Moreover, in the case of observations, derived indices may be easier to obtain than is the case with daily temperature and precipitation data, which are not always distributed by meteorological services. Peterson and Manton (2008) discuss collaborative international efforts to monitor extremes by employing extreme indices. Typically, although not exclusively, extreme indices used in the scientific literature reflect "moderate" extremes, e.g., events occurring as often as 5% or 10% of the time. More extreme "extremes" can be better investigated using Extreme Value Theory (see below). Extreme indices are more generally defined for (daily) temperature and precipitation characteristics, and are rarely applied to other weather and climate variables, such as wind speed, humidity, or physical impacts and phenomena. Some examples are available in the literature for wind-based (Della-Marta et al., 2009) and pressure-based (Beniston, 2009a) indices, for health-relevant indices combining temperature and relative humidity characteristics (e.g., Diffenbaugh et al., 2007; Fischer and Schär, 2010), and for a range of dryness indices (see Box 3.2).

Extreme Value Theory (EVT) is another (more general) approach used for the evaluation of changes in extremes (e.g., Coles, 2001). EVT aims at deriving a probability distribution of events from the tail of a probability distribution, that is, for very low-probability (or "rare") events (typically occurring less frequently than once per year or per period of interest). Theory is used to derive a complete probability distribution for such low-probability events, which then allows also for analyzing the probability of occurrence of events which are outside of the observed data range. Two different approaches can be used to estimate the parameters for such probability distributions. In the *block maximum approach*, the probability distribution parameters are estimated for maximum values of consecutive blocks of a time series (e.g., years). In the second approach, instead of the block maxima the estimation is based on events which exceed a high threshold (*peaks over threshold* approach). Both approaches are used in climate research.

Another test for changes in extremes that has been proposed in recent years is the "iid-test" (Benestad, 2003, 2006), which investigates the occurrence probability of new record values in a time series of independent and identically distributed random variables. The iid-assumption implies stationarity of the time series. If observed records in a time series contradict the iid assumption, stationarity is not evident. For instance, Benestad (2004) reported that the monthly record temperatures at the end of the 20th century from 17 stations worldwide were higher than could be expected from stationary time series.

Beside the actual magnitude of extremes (quantified in terms of probability/return frequency or absolute threshold), other relevant aspects for the definition of climate extremes from an impact perspective include the event's duration, the 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).

These aspects, together with seasonal variations in climate extremes, are rarely examined in climate models or observational analyses, and thus can only be partly assessed within this chapter.

To conclude, it is difficult to precisely define an extreme (e.g., Stephenson et al., 2008a) and we note limitations in the definition of both probability-based or threshold-based climate extremes and their relations to impacts, which apply independently of the chosen method of analysis:

- An event with low probability is not necessarily extreme in terms of impact
- Impact-related thresholds can vary in space and time, i.e., single absolute thresholds (e.g., a daily rainfall exceeding 25 mm or the number of frost days) will not reflect extremes in all locations and time periods (e.g., season, decade)

Orlowsky and Seneviratne (2011) illustrate these issues, by comparing projections of changes in (annual) heatwave length between 1980-2000 and 2080-2100. They compare projected changes in three different indices:

1. HWDImax or the maximum heatwave duration index (used e.g., in Frich et al., 2002; or Tebaldi et al., 2006), which is defined as the maximum length of periods of at least 5 days with a maximum air temperature (Tmax) that is 5°C higher than the climatology for that day;
2. HWDImean or the mean heatwave duration index defined as the mean length of periods of at least 5 days with Tmax that is 5°C higher than the climatology;
3. WSDI or the warm spell duration index defined as the fraction of days per year which belong to spells of at least 6 days with Tmax higher than its 90th percentile during the 1961-1990 base period (used in e.g., Alexander et al., 2006).

All three indices indicate that heatwave length is projected to increase in the models for most regions. However, the magnitude and regional patterns of the changes depend on the chosen index. The HWDImax index is not statistically robust, because it can produce many zero values for the present day in some locations, such as the tropics, where the variability of daily temperature is low (Alexander et al., 2006). To overcome this, the WSDI (percentile based threshold) has been suggested as alternative. However, this index results in very large changes in the tropics because the 90th percentile values are close to the mean value of the Tmax distributions, and thus this value is easily exceeded with the projected warming. While a typical 90th percentile value in the time frame 1961-1990 may be considered as extreme for that period, in a statistical sense, one cannot exclude the possibility that society could adapt to such temperatures, especially if it is not very far away from the mean. So the choice of using either the mean heatwave duration or the maximum heatwave duration using the same heatwave definition can lead to marked differences in projected changes. Finally, none of these indices allow us to assess changes in the intrinsic persistence of temperature extremes (i.e., the tendency for clustering of hot days, independent of changes in the number of hot days), which may be more relevant for certain impacts (e.g., Lorenz et al., 2010). Similar definition issues apply to other types of extremes, especially those characterizing dryness (see Section 3.5.1 and Box 3.2).

3.1.3. Compound (Multiple) Events

In climate science, compound events can be two or more extreme events, or combinations of extreme events with amplifying events or conditions, or combinations of events which are not themselves extremes but lead to an extreme event or impact when combined. The contributing events can be of similar (clustered multiple events) or different type(s). There are several varieties of clustered multiple events, such as tropical cyclones generated a few days apart with the same path and/or intensities, which may occur if there is a tendency for persistence in atmospheric circulation and genesis conditions. Examples of compound events resulting from events of different types are varied: for instance, high sea level coinciding with tropical cyclone landfall, or a combined risk of flooding from sea level surges and precipitation-induced high river discharge (Van den Brink et al., 2005). Compound events can even result from "contrasting extremes": e.g., the projected near-simultaneous occurrence of both droughts and heavy precipitation events in the future climate of Central Europe, (Table 3.3), or, more anecdotally, flash flooding following bushfires (due to fire-induced thunderstorms from pyrocumulus clouds (e.g., Tryhorn et al., 2008)).

Impacts on the physical environment (Section 3.5) are often the result of compound events. For instance, floods will more likely occur over saturated soils (Section 3.5.2), which means that both soil moisture status and precipitation intensity play a role. The wet soil may itself be the result of a number of above-average but not necessarily extreme precipitation events, or of enhanced snow melt associated with temperature anomalies in a given season. Similarly, droughts are both the result of pre-existing soil moisture deficits and of the accumulation of precipitation deficits and evapotranspiration excesses (Box 3.2), not all (or none) of which are necessarily extreme for a particular drought event when considered in isolation.

More generally, the following causes for a correlation between the occurrence of extremes (or their impacts) can be identified:

1. a common external forcing factor for changing the probability of the two events (e.g., regional warming, change in frequency or intensity of El Niño events)
2. mutual reinforcement of one event by the other and vice versa due to system feedbacks (Section 3.1.4)
3. conditional dependence of the occurrence or impact of one event on the occurrence of another event (e.g., extreme soil moisture levels and precipitation conditions for floods, droughts, see above)

Changes in one or more of these factors would be required, if a changing climate was to see changes in the occurrence of compound events. Unfortunately, investigation of possible changes in these factors has received little attention.

Much of the analysis of changes of extremes has, up to now, focused on individual extremes of a single variable. However, recent literature in climate research is starting to consider compound events. Compound events imply multivariate probability distributions, which can be transformed into copulas (that is, multivariate distributions, of which the marginal distributions are uniform). Schölzel and Friederichs (2008) provide an introduction to the copula approach for climate research, and an application of a Gaussian copula for multivariate hydrological extremes in France is described in Renard and Lang (2007). More general literature on multivariate extreme value theory and the statistics of multivariate extremes is provided in e.g., Coles (2001) and Beirlant et al. (2004). A more traditional approach using multivariate histograms and empirical conditional probability estimates is taken in Benestad and Haugen (2007), which analyze the relation of flood hazards with spring temperature and precipitation in Norway. In another study, Beniston (2009b) analysed changes in combined extremes (warm/dry, warm/wet, cold/dry, cold/wet) in Europe. Also, Bayesian approaches have been used to construct joint probability distributions of temperature and precipitation changes (Murphy et al., 2007; Tebaldi and Sanso, 2009).

3.1.4. Feedbacks

A special case of compound events is related to the presence of feedbacks within the climate system, i.e., mutual interaction between several climate processes, which can either lead to a damping (negative feedback) or enhancement (positive feedback) of the initial response to a given forcing. Feedbacks can play an important role in the development of extreme events, and in some cases two climate extremes can mutually strengthen one another.

One example of positive feedback between two extremes is the mutual enhancement of droughts and heatwaves in transitional regions between dry and wet climates (Seneviratne et al., 2010). This feedback has been identified as an influence on projected changes in temperature variability and heatwave occurrence in Central and Eastern Europe (Seneviratne et al., 2006a; Diffenbaugh et al., 2007), and possibly also in Britain, Eastern North America, the Amazon and East Asia (Brabson et al., 2005; Clark et al., 2006), as well as for past heatwaves and temperature extremes in Europe and the United States (Durre et al., 2000; Fischer et al., 2007a; 2007b; Hirschi et al., 2011). The two mechanisms underlying this feedback are:

1. the enhancement of soil drying with enhanced temperature (due to the higher vapour pressure deficit and its impact on evapotranspiration); and
2. the enhancement of the temperature anomalies when soil moisture deficit limits evapotranspiration and thus leads to an enhancement of sensible heat flux.

This effect is expected to play a role mostly in transitional climate regions (which are seasonally dry), since these regions are characterized by a stronger coupling of evapotranspiration with soil moisture (Koster et al., 2004b). Climate change may also lead to a shift in the location of these regions (Seneviratne et al., 2006a), and land cover may influence these feedbacks (Teuling et al., 2010). Hirschi et al. (2011) illustrate this effect for the case of Southeastern Europe, based on observational data over the time period 1961-2000. They calculate quantile regressions of the percentage of hot days (%HD) in summer in Southeastern Europe as functions of a drought index (the standardized precipitation index or SPI, see also Box 3.2) and show a pronounced widening of the %HD distribution with drier conditions. Additionally, there may also be indirect and/or non-local effects of dryness on heatwaves through e.g., changes in circulation patterns or dry air advection (e.g., Fischer et al., 2007a; Vautard et al., 2007; Haarsma et al., 2009).

Also feedbacks between trends in snow cover and changes in temperature extremes are known to be highly relevant for projections (e.g., Kharin et al., 2007; Orlowsky and Seneviratne, 2011). Both these feedbacks with soil moisture and snow affect extremes in some regions (hot extremes in transitional climate regions, and cold extremes in snow-covered regions), and thus may induce significant deviations of changes in extremes versus changes in the average climate, as also discussed in Section 3.1.6.

Other relevant feedbacks involving extreme events are those that can lead to impacts on the global climate, such as modification of land carbon uptake due to enhanced drought occurrence (e.g., Ciais et al., 2005; Friedlingstein et al., 2006; Reichstein et al., 2007), or the possible release of greenhouse gases with melting of permafrost and lakes in high-latitude regions (Davidson and Janssens, 2006; Walter et al., 2006). These aspects are not, however, considered in this chapter.

3.1.5. Confidence and Likelihood of Assessed Changes in Extremes

In this chapter, all assessments regarding past or projected changes in extremes are expressed following the new IPCC AR5 uncertainty guidance (Mastrandrea et al., 2010). The new uncertainty guidance makes a clearer distinction between confidence and likelihood but may complicate comparisons between assessments in this chapter and those in the IPCC AR4. The following procedure was followed here (see in particular Executive Summary and Tables 3.1, 3.2 and 3.3.):

- For each assessment, the confidence level for the given assessment is assessed (*low*, *medium* or *high*).
- For assessments with *high confidence*, likelihood assessments of a direction of change are also provided (*virtually certain* for 99%-100%, *very likely* for 90-100%, *likely* for 66-100%, *more likely than not* for 50-100%, *about as likely as not* for 33-66%, *unlikely* for 0-33%, *very unlikely* for 0-10%, and *extremely unlikely* for 0-1%).
- For assessments with *medium confidence*, a direction of change is provided, but without an assessment of likelihood (which we consider here to be equivalent to "more likely than not" likelihood assessments in the AR4, IPCC, 2007a).
- For assessments with *low confidence*, no direction of change is generally provided.

The confidence assessments are expert-based evaluations which consider the confidence in the tools and data basis (models, data, proxies) used to assess or project changes in a specific element, and the associated level of understanding. Examples of cases of *low confidence* for model projections are if models display poor performance in simulating the specific extreme in the present climate (see also Box 3.1), or if insufficient literature on model performance is available for the specific extreme, e.g., due to lack of observations. Similarly for observed changes, the assessment may be of *low confidence*, if the available evidence is based only on scattered data (or publications) that are insufficient to provide a robust assessment for a large region, or the observations may be of poor quality, not homogeneous, or only of an indirect nature (proxies). In cases with *low confidence* regarding past or projected changes in some extremes, we specify whether the *low confidence* is due to lack of literature, lack of evidence (data, observations), or lack of understanding. Cases of changes in extremes for which confidence in the models and data is rated as "*medium*" are those where we have some confidence in the tools and evidence available to us, but there remain substantial doubts about some aspects of the quality of these tools. **It should be noted that an assessment of *low confidence* in projections of a specific extreme neither implies nor excludes the possibility of changes in this extreme. Rather the assessment indicates low confidence in the ability to project any such changes**.

Changes (observed or projected) 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 3.1). 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. Overall, we can infer that **our confidence in past and future changes in extremes varies with the type of extreme, as well as the considered region and season, linked with the level of understanding and reliability of simulation of the underlying processes**. These various aspects are addressed in more detail in Box 3.1, Section 3.2 and the individual sections on specific extremes in Sections 3.3 to 3.5.

[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.]

3.1.6. Changes in Extremes and Their Relationship to Changes in (Regional and Global) Mean Climate

Changes in extremes can be caused by changes in the mean, variance or skewness of probability distributions, or all of these. 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, and/or from a change in the variance and/or skewness of the frequency distribution of daily maximum temperatures. 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 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 naive extrapolation would be less appropriate or possibly even misleading (e.g., Ballester et al., 2010).

The results of both empirical and model studies indicate that although in several situations extremes do scale closely with the mean (e.g., Griffiths et al., 2005), **there are sufficient exceptions from this that changes in the variability and shape of probability distributions of weather and climate variables need to be considered as well as changes in means, if we are to project future changes in extremes** (e.g., Caesar et al., 2006; Della-Marta et al., 2007b; Brown et al., 2008; Ballester et al., 2010; Orlowsky and Seneviratne, 2011). This appears to be especially the case for short-duration precipitation, and for temperatures at urban locations and in mid- and high-latitudes (but not all locations in these regions). In mid- and high-latitudes stronger increases (or decreases) of some extremes are generally associated with feedbacks with soil moisture or snow cover (Section 3.1.4).

An additional relevant question is the extent to which regional changes in extremes scale with changes in global mean temperature, since several studies focus on the latter (i.e., specific global mean temperature "targets", such as a 2°C target, e.g., Allen et al., 2009; Meinshausen et al., 2009). As an example, Figure 3.1. displays the scaling between projected changes in the 10th and 90th percentile of Tmax on annual and seasonal (JJA, DJF) time scales with globally-averaged annual mean changes in Tmax. This scaling encompasses the effects of the scaling of regional changes with global changes, of changes in extreme quantiles with mean changes (see above), and for JJA and DJF of seasonal changes with annual mean changes (e.g., Orlowsky and Seneviratne, 2011). As seen in the figure, the scaling is rarely equal to 1, and for the 90th percentile is almost always larger than 1. This figure again highlights the particularly large projected changes in the 10th percentile Tmax in the northern high-latitude regions in winter and the 90th percentile Tmax in Southern Europe in summer (associated with snow cover and soil moisture feedbacks, respectively, Section 3.1.4), with scaling factors of up to 2.5. However, in some regions and seasons, the scaling can also be below 1 (e.g., changes in 10th percentile in JJA in the high latitudes). The lack of scaling between regional and seasonal changes in extremes and changes in means as also been highlighted in empirical studies (e.g., Caesar et al., 2006). **It should further be noted that not only do extremes not necessarily scale with mean changes, but also mean global warming does not exclude cooling in some regions and seasons**: It has for instance been recently suggested that the decrease in sea ice induced by the mean warming could induce more frequent cold winter extremes over northern continents (Petoukhov and Semenov, 2010). Also parts of Central North America and the Eastern United States present cooling trends in mean temperature and some temperature extremes in the spring to summer season (Section 3.3.1). Several mechanisms have been proposed for this cooling trend (e.g., Pan et al., 2004; Portmann et al., 2009).

[INSERT FIGURE 3.1 HERE
Figure 3.1: Scaling between globally-averaged annual mean projected change in Tmax and spatial changes in seasonal (DJF, top; JJA, bottom) changes in 10%ile (left) or 90%ile (right) of Tmax, CMIP3 projections, 2080-2100 time frame minus 1980-2000 time frame (A2 vs 20C3M). The 10%ile and 90%ile values are computed from pooling all data for the respective months in the two 20-year periods. (adapted from Orlowsky and Seneviratne, 2011)]

3.1.7. Surprises

This report focuses on the most likely changes in extremes based on current knowledge. **However, the possible future occurrence of low-probability high-impact scenarios associated with the crossing of poorly understood thresholds cannot be excluded, given the transient and complex nature of the climate system**. So, an assessment that we have *low confidence* in projections of a specific extreme, or even lack of consideration of given climate changes under the categories covered in this chapter (e.g., shutdown of meridional overturning circulation), should not be interpreted as meaning that no change is expected in this extreme or climate element (see also Section 3.1.5). Non-linear feedbacks play an important role in either damping or enhancing extremes in several climate variables (Section 3.1.4), and this can also lead to "surprises", i.e., changes in extremes greater (or less) than might be expected with a gradual warming of the climate system. Similarly, as discussed in 3.1.3, contrasting or multiple extremes can occur but our understanding of these is insufficient to provide credible comprehensive projections of risks associated with such combinations.

One aspect that we do not address in this chapter is the existence of possible tipping points in the climate system (e.g., Lenton et al., 2008; Scheffer et al., 2009), that is, the risks of abrupt, possibly irreversible changes in the climate system. Scheffer et al. (2009) illustrate the possible equilibrium responses of a system to forcing. In the case of a linear response only a large forcing can lead to a major state change in the system, and this change is potentially reversible. However, in the presence of a critical threshold even a small change in forcing can lead to a major (reversible) change in the system. For systems with critical bifurcations in the equilibrium state function two alternative stable conditions may exist, whereby an induced change may be (temporarily or permanently) irreversible. Such critical transitions within the climate system represent typical low-probability high-risks scenarios, which cannot be excluded at present. Lenton et al. (2008) provided a recent review on tipping elements within the climate system, i.e., sub-systems of the Earth system that are at least sub-continental in scale and which entail a tipping point. They identified the following tipping elements for the Earth's climate system: the Greenland ice sheet, the Arctic summer sea-ice, the West Antarctic ice sheet, the Atlantic thermohaline circulation, El Niño – Southern Oscillation, the Indian summer monsoon, the Sahara/Sahel and West African monsoon, the Amazon rainforest, and the boreal forest. Some of these would be especially relevant to certain extremes (e.g., El Niño – Southern Oscillation for drought, and the ice sheets for sea level extremes), or are induced by changes in extremes (e.g., Amazon rainforest die-back induced by drought). For some of the tipping elements, the existence of bistability can be inferred from paleo records. There is often a lack of agreement between models regarding these high-risk low-probability scenarios, for instance regarding a possible die-back of the Amazon rainforest (Friedlingstein et al., 2006) or the risk of an actual shutdown of the Atlantic thermohaline circulation (e.g., Lenton et al., 2008). Scheffer et al. (2009) have recently suggested the existence of early signs for approaching critical transitions.

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 Table 3.2. In this sub-section issues are discussed related to the data and observations used to examine observed changes in extremes.

Issues with data availability are especially critical when examining 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). Another important criterion constraining data availability for the analysis of extremes is the respective time scale on which they occur (Sections 3.1.2), 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 (see Box 3.2) and unusually wet periods on the order of a month or longer. To examine changes in extremes occurring on short time scales, particularly of climate elements such as temperature and precipitation (or wind), 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. Even where sufficient data are available, several problems can still limit their analysis. First, although the situation is changing (especially for the situation with respect to “extreme indices”, Section 3.1.2), 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 (see below). These and other issues are discussed in detail in the AR4 (Trenberth et al., 2007). For instance, the temperature and precipitation stations considered in the daily dataset used in Alexander et al. (2006) are not globally uniform, and measurements are in particular found to be lacking in Northern South America, Africa, and part of Australia. The other commonly used dataset from Caesar et al. (2006; used e.g., in Brown et al., 2008) has additional data gaps in most of South America, Africa, Eastern Europe, Mexico, the Middle East, India, and Southeast Asia. Also the study by Vose et al. (2005) has data gaps in South America, Africa and India. It should be further noted that the regions with data coverage do not all have the same density of stations (Alexander et al., 2006; Caesar et al., 2006). While some studies are available on a country- or regional basis for areas not covered in global studies, nevertheless lack of data leads to limitations in our ability to assess observed changes in climate extremes for many regions

Whether or not climate data are homogeneous is of strong relevance for 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. Some meteorological elements are especially vulnerable to uncertainties caused by even small changes in the exposure of the measuring equipment. For instance, erection of a small building or changes in vegetative cover near the measuring equipment can produce a bias in wind measurements (Wan et al., 2010). 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 techniques applicable to 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. Homogeneity issues also 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, tornadoes and related phenomena 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 extratropical cyclones, 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 extratropical cyclones and other climate features (Compo et al., 2006). Results, however, are strongly dependent on the reanalysis and cyclone tracking techniques used (Ulbrich et al., 2009).

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 some basins 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 North 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 (Box 3.2). 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 above-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 and progress has been made in the last 15 years (e.g., Caesar et al., 2006; Brown et al., 2008). 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). 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.

[INSERT FIGURE 3.2 HERE
Figure 3.2: Definitions of regions used in Tables 3.2 and 3.3.]

[INSERT TABLE 3.2 HERE
Table 3.2: Regional observed changes in temperature and precipitation extremes, including dryness. See Figure 3.2 for definitions of regions.]

3.2.2. The Causes Behind the Changes

This section discusses the main requirements, approaches, and considerations for the attribution of causes for observed changes in extremes. In Sections 3.3. to 3.5, the causes for observed changes in specific extremes are assessed. A global summary of these assessments is provided in Table 3.1

3.2.2.1. Why Extremes Change and What are the Possible Causes

Climate variations and change are induced by variability internal to the climate system, and 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, and land use and land cover changes. The mean state, extremes, and variability are all related aspects of the climate, so changes that affect the mean climate would in general result in changes in extremes. For this reason, we provide in section 3.2.2.2 a brief overview of human-induced changes in the mean climate to aid the understanding of changes in extremes as the literature directly addressing the causes of changes in extremes is quite limited.

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 external forcings affecting extremes include the overall increases in temperature induced by changes in radiation, the enhanced humidity content of the atmosphere, the increased land-sea contrast in temperatures, which can, e.g., affect circulation patterns and in particular monsoons. On the regional and local scales, additional processes can modulate the overall changes in extremes, including regional feedbacks, in particular linked to land-atmosphere interactions with e.g., soil moisture or snow (e.g., Section 3.1.4). This section briefly reviews the current understanding of the causes (i.e., in the sense of attribution to either external forcing or internal climate variability) 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 in the second half of the 20th century, we base our analysis on the following AR4 assessment (IPCC, 2007a): Most of the observed increase in global average temperatures is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations. Greenhouse gas forcing alone 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 can be explained without external forcing, and *very unlikely* that it is due to known natural external causes alone. Anthropogenically-forced warming over the second half of the 20th century has also been detected in all continents, in addition to the global-scale attribution (Hegerl et al., 2007; Gillett et al., 2008b).

Overall, attribution at scales smaller than continental, with limited exceptions (below), 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 driving processes (either attributable to external forcing or internal climate variability) at these scales. Moreover, averaging over smaller regions reduces the internal variability less than does averaging over large regions. In addition, the small-scale details of external forcing, and the responses simulated by models are less credible than large-scale features: For instance, temperature changes are poorly simulated by models in some regions and seasons (Dean and Stott, 2009; van Oldenborgh et al., 2009). Also 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). Nonetheless, recent work has expanded the literature and showed more evidence of detection of an anthropogenic influence at increasingly smaller spatial scales and for seasonal averages (Stott et al., 2010). For instance, Min and Hense (2007) found that anthropogenic forcing as opposed to alternative explanation such as natural external forcing or internal variability was required for most continent-season temperature changes in multi-model estimates from the CMIP-3 ensemble to best match the observed changes. An anthropogenic signal was detected in 20th century summer temperatures in each of 14 Northern Hemispheric sub-continental regions except central North America, although the results were more uncertain when anthropogenic and natural signals were considered together (Jones et al., 2008). An anthropogenic signal has also been detected in multi-decadal trends of a U.S. climate extreme index (Burkholder and Karoly, 2007), in the hydrological cycle of the western United States (Barnett et al., 2008), in New Zealand temperatures (Dean and Stott, 2009), and in Europe (Christidis et al., 2011).

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. 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), and at the largest spatial-temporal scales moistening is close to the Clausius-Clapeyron scaling of the saturated specific humidity (~7%/K, Willett et al., 2010), though relative humidity over low- and mid-latitude land areas decreased over a 10-year period prior to 2008 possibly due to slower temperature increase in the oceans than over the land (Simmons et al., 2010). 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).

The increase in the atmospheric moisture content would be expected to lead to an increase in extreme precipitation. 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; Haerter and Berg, 2009; Lenderink and van Meijgaard, 2009). The influence of anthropogenic forcing has been detected in the pattern of land precipitation trends though the model-simulated magnitude of changes is smaller than that observed (Zhang et al., 2007a). Because models do not simulate exactly the same spatial pattern of precipitation trends, the simple averaging of those patterns from model simulation in Zhang et al. (2007a) would tend to reduce the model signal. 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., 2008). 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 a Change in Extremes to Causes

The guidance paper on detection and attribution (Hegerl et al., 2010) from the joint IPCC WGI/WGII expert meeting on detection and attribution (Sept. 14-16, 2009) provides detailed guidance on the procedures that include two main approaches to attribute a change in climate to causes. One is single-step attribution that 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. The alternate procedure is multi-step attribution that combines an assessment that attributes an observed change in a variable of interest to a change in climate, with a separate assessment that attributes the change in climate to external forcings. Attribution of changes in climate extremes has some unique issues. Observed data are limited in both quantity and quality (Section 3.2.1), resulting in uncertainty in the estimation 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. On the other hand, GCMs have several issues simulating extremes (Section 3.2.3).

Single-step attribution based on optimal detection and attribution (e.g., Hegerl et al., 2007) can in principle be applied to climate extremes. However, the difference in statistical properties between mean values and extremes needs to be carefully addressed (e.g., Zwiers et al., 2011; see also Section 3.1.6). 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 make it possible to directly compare observed extremes with climate model results. For example, sea level pressure simulated by multiple GCMs 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., 2009d). GCM-simulated precipitation and temperature have been downscaled 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 this enabled a detection and attribution analysis on human-induced changes in these variables (Barnett et al., 2008)

If a single-step attribution of causes to effects on extremes or physical impacts of extremes is not feasible, it might be feasible to conduct a multiple-step attribution. The assessment would then need to be based on evidence not directly derived from model simulations, physical understanding and expert judgement, or their combination. 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). A change in streamflow may be attributable to external 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. In cases where the underlying physical mechanisms are less certain, such as those linking tropical cyclones and sea surface temperature (see section 3.4.4), the confidence in multi-step attribution can be severely undermined. 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).

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 external forcing (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 (e.g., Stott et al., 2004; Pall et al., 2011).

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 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, also referred to as General Circulation Models (GCMs); downscaling of GCM-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, GCMs were the main source of globally-available regional information on the range of possible future climates including extremes (Christensen et al., 2007). This is still the case for many regions, as can be seen in Table 3.3.

State-of-the-art GCMs 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. In particular, the AR4 demonstrated that global statistics of extreme events for present day climate are surprisingly well simulated by current GCMs considering their resolution and large-scale systematic errors (Randall et al., 2007). 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. Much of the signal from climate change simulations is sensitive to model parameterization schemes (e.g., radiation, land-surface, and cloud schemes). Furthermore, the assessment of climate model performance with respect to extremes (summarised in Sections 3.3 to 3.5 for specific 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 (Section 3.2.1).

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, to simulate weather and climate at finer spatial resolutions than is possible with GCMs – a step which is particularly relevant for many extremes given their spatial scale. They are, nonetheless, constrained by the reliability of large-scale information coming from the GCMs. Recent advances in downscaling for extremes are discussed below. However, as global models continue to develop, and their spatial resolution as well as their complexity continues to improve, they will become 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.

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-50 km, but in some cases down to 10-15 km (e.g., Dankers et al., 2007), to represent regional sub-domains, using either observed (reanalysis) or lower-resolution GCM data to provide their boundary conditions. Using non-hydrostatic mesoscale models, applications at 1-5 km resolution are also possible for shorter periods (typically a few months, a few full years at most) – a scale at which clouds and convection can be resolved and the diurnal cycle tends to be better resolved (e.g., Grell et al., 2000; Hay et al., 2006; Hohenegger et al., 2008). 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 latter have been run at 20 km globally in the case of the ‘super-high’ resolution simulations (Kamiguchi et al., 2006; Kitoh et al., 2009; Kim et al., 2010).

The main advantage of dynamical downscaling is its potential for capturing mesoscale nonlinear effects and providing information for many climate variables at a relatively high spatial resolution, while ensuring that such information is internally consistent within the physical constraints of the model. For many users, the main drawbacks of dynamical models for downscaling 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). RCMs provide area-averaged precipitation which means a tendency to more days of light precipitation (Frei et al., 2003; Barring et al., 2006) and reduced magnitude of extremes (Chen and Knutson, 2008; Haylock et al., 2008) compared with point values. Other concerns with RCMs are that they may involve different parameterization schemes to the driving models and most currently do not include coupling between ocean and atmosphere (Wang et al., 2004). Moreover, questions remain about RCM domain size and the extent to which RCM features, like biases, are inherited from the driving model, and the implications of these issues for the credibility of the RCM projections (Wang et al., 2004; Laprise et al., 2008).

Statistical downscaling methods use relationships between the large-scale circulation (predictands) and local-scale surface variables (predictors) that have been derived from observed data, and apply these to climate model data (Christensen et al., 2007). They may 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 Europe (e.g., Schmidli et al., 2007), 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 North America (e.g., Vrac et al., 2007; Dibike et al., 2008). Statistical downscaling methods have the advantage to users of being computationally inexpensive, 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) or distribution functions of extremes can be simulated (Benestad, 2007). 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, 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 analog 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 (Charles et al., 1999; Hewitson and Crane, 2006). Finally, a potential limitation of statistical downscaling methods is that their calibration is necessarily based on present (and past) climate, and they may thus not be able to capture changes in extremes that are induced by mechanistic changes in regional (or global) climate. There have been few systematic inter-comparisons of dynamical and statistical downscaling approaches 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.

In terms of temporal resolution, while GCMs 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 (i.e., non-cloud/convection resolving scales) they do not adequately represent sub-daily precipitation and the diurnal cycle of convection (Gutowski et al., 2003; Brockhaus et al., 2008; Lenderink and Van Meijgaard, 2008). 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, although some weather generators, for example, do provide hourly information (Maraun et al., 2010).

For reasons of space, it is not possible in this chapter to provide assessments of projected changes in extremes at scale finer than regional (Table 3.3.). Several countries, in particular in Europe, have, however, developed their own national projections, including information about extremes, and a range of other high-resolution information and tools are available from national weather and hydrological services and academic institutions to assist users and decision makers.

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.

As was noted in Section 3.2.3.1, most shortcomings in GCMs and in 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). Some processes – particularly those involving feedbacks (Section 3.1.4), and this is especially the case for climate extremes and associated impacts - are still poorly represented and/or understood (e.g., land-atmosphere interactions, stratospheric processes, blocking dynamics) despite some improvements in the simulations of others (see Box 3.1 and below). Therefore, limitations in computing power and in the scientific understanding of some physical processes, currently restrict further global and regional model improvements. In addition, uncertainty due to structural or parameter errors in GCMs propagates directly from global model simulations as input to downscaling models and thus to downscaled information.

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 with approximately 20 km horizontal resolution still do not resolve the atmospheric processes 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 GCMs and of most current RCMs (and even numerical weather prediction models). Extremes may also be impacted by mesoscale circulations that GCMs 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 relevant 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 3.1). Confidence and credibility in projected changes in extremes increase when the physical mechanisms producing extremes in models are considered reliable, such as increases in specific humidity in the case of the projected increase in the proportion of summer precipitation falling as intense events in Central Europe (Kendon et al., 2010). 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 nonetheless be stressed that physical consistency of simulations with observed behaviour provides only necessary and not sufficient evidence for credible projections (Gutowski et al., 2008a).

While downscaling provides more spatial detail, the added value of this step needs to be assessed (Benestad et al., 2007; Laprise et al., 2008), keeping in mind that an overfitted model may perform well for present climate but will not be credible for future projections. Spatial inhomogeneity of both land-use/land-cover and aerosol forcing, adds to regional uncertainty. This means that the factors inducing uncertainty in the projections of extremes in different regions may differ considerably. Specific issues inducing uncertainties in RCM projections are the interactions with the driving GCM, especially in terms of biases and climate-change signal (e.g., Déqué et al., 2007; de Elía et al., 2008; Laprise et al., 2008; Kjellstrom and Lind, 2009) and the choice of regional domain (Wang et al., 2004; Laprise et al., 2008). In the case of statistical downscaling, uncertainties are induced by the choice of domain size (Benestad, 2001) together with the choice of predictors themselves (Charles et al., 1999; Hewitson and Crane, 2006) and the underlying assumption of stationarity (Raje and Mujumdar, 2010). For both dynamical and statistical downscaling, uncertainties are also inherited from the GCMs that provide the large-scale changes driving the downscaling models.

For many user-driven applications, impact models need to be included as an additional step for projections (e.g., hydrological or ecosystem models). Because of the mentioned issues of scale discrepancies and overall biases, it is necessary to bias correct RCM data before input to some impacts models (i.e., to bring the statistical properties of present-day simulations in line with observations and to use this information to correct projections). A number of bias correction methods, including quantile mapping and gamma transform, have recently been developed and indicate promising skill for extremes of daily precipitation (Piani et al., 2010; Themeßl et al., 2011).

In conclusion, it has been recommended (Knutti et al., 2010b) that the following four factors should be considered in assessing the likely future climate change in a region: historical change, process change, global climate change projected by GCMs, and downscaled projected change. Consistency and comprehensiveness of the physical and dynamical basis of the projected climate response across models and methods should be evaluated. Moreover, model evaluation, detection and attribution, observations and projections are intimately linked, and assessments of climate projections would benefit from a tighter integration of these topics (Knutti et al., 2010a). How to address this issue in the context of extremes is discussed further in the next section.

3.2.3.3. Ways of Exploring and Quantifying Uncertainties

Uncertainties can be explored, and quantified to some extent, through the 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 (i) collecting results from a range of models from different modelling centres (multi-model ensembles), to include the impact of structural model differences, (ii) by generating simulations with different initial conditions (intra-model ensembles) to characterize the uncertainties due to internal climate variability, or (iii) varying multiple internal model parameters within plausible ranges (perturbed and stochastic physics ensembles), with both (ii) and (iii) aiming to produce a more systematic estimate of single model uncertainty (Knutti et al., 2010b).

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 GCM 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 CMIP3 MME – Coupled Model Intercomparison Project 3 multi-model ensemble) were made available at the Program for Climate Model Diagnosis and Intercomparison (PCMDI, http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). 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. GCMs are expensive to run, and thus a compromise is needed between the number of models, number of simulations and the complexity of the models (Knutti, 2010). The Coupled Model Intercomparison Project Phase 5 multi-model ensemble (CMIP5 MME) is currently being implemented and will provide a new framework for coordinated climate change experiments for the next five years.

Besides the uncertainty due to randomness itself, which is the canonical statistical definition, it is important to distinguish between the uncertainty due to *insufficient agreement* in the model projections, the uncertainty due to *insufficient evidence* (insufficient observational data to constrain the model projections or insufficient number of simulations to infer projections or insufficient lack of understanding of the physical processes), and the uncertainty induced by *insufficient literature*, which refers to the lack of published analyses of projections. 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).

Uncertainty analysis of the CMIP3 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 was larger than the standard deviation, the signal was 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, the ensemble was strictly an “ensemble of opportunity”, without sampling protocol and the possible dependence of different models on one another (e.g., due to shared parameterizations) was not assessed (Knutti et al., 2010a). Furthermore, this particular metric, that assesses sign agreement only, can provide misleading conclusions in cases, for example, where the projected changes are near zero. We nonetheless use a similar metric in several of the figures of the IPCC SREX (indicating “likely” changes when at least 66% of the models agree on the sign of change).

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 probability distributions (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 used to examine projected changes in extremes and their uncertainties (Barnett et al., 2006; Clark et al., 2006; Burke and Brown, 2008; Clark et al., 2011). Advances have also been made in developing probabilistic information at regional scales from the AOGCM simulations, but there has been rather less development extending this to probabilistic downscaled regional information and to extremes (Fowler et al., 2007b; Fowler and Ekstrom, 2009). One recent example of such projections provides probability distributions of changes in various parameters including the wettest and hottest days of each season for 25 km grid squares across the UK (Murphy et al., 2009). In general, downscaling methods are maturing and being more widely applied (despite being still restricted in terms of geographical coverage, Maraun et al., 2010).

Both statistical and dynamical downscaling methods are affected by the uncertainties which affect the global models, and a further level of uncertainty associated with the downscaling step also needs to be taken into consideration (see also Sections 3.2.3.1 and 3.2.3.2). The increasing availability of coordinated RCM simulations for different regions permits more systematic exploration of dynamical 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 co-ordinated simulations is made available at the daily timescale, facilitating the analysis of some extreme events. 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 to the spectrum of variability on at least multi-annual timescales and potentially up to multi-decadal timescales in the case of European projections of precipitation extremes (Kendon et al., 2008). Some comparisons between statistical and dynamical downscaling results are available but scarce (Section 3.2.3.1).

START BOX 3.1 HERE

Box 3.1: Variations in Confidence in Projections of Climate Change: Mean vs. Extremes, Variables, Scale

Comparisons of observed and simulated climate demonstrate good agreement for some climate variables such as mean temperature, especially at large horizontal scales (e.g., Räisänen, 2007). For instance, Figure 9.12 of the AR4 (Hegerl et al., 2007) compares the ability of 14 climate models to simulate the decadal variations of mean temperature through the 20th century. When the models included both natural and anthropogenic forcings, they consistently reproduced the decadal variations in global mean temperature. 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 (Figure 9.12, Hegerl et al., 2007). 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 temperature signal expected from anthropogenic factors is large relative to the model uncertainty and the natural variability, compared with higher latitudes. Figure 9.12 from AR4 (Hegerl et al., 2007) also shows 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.

Uncertainty in projections also depends on the considered variables, phenomena or impacts (Sections 3.3. to 3.5.). There is more model uncertainty for variables other than temperature, for instance precipitation (Räisänen, 2007; Hawkins and Sutton, 2011, see also Section 3.2.3). And the situation is more difficult again for extremes. For instance, climate models simulate observed changes in extreme temperatures relatively well, but the frequency, distribution and intensity of heavy precipitation is more poorly simulated (Randall et al., 2007) as are observed 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; Orlowsky and Seneviratne, 2011) and significant inconsistencies are also found for projections of agricultural (soil moisture) droughts (Wang, 2005; see also Box 3.2). 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.

The relative importance of various causes of uncertainties in projections is somewhat different for earlier compared with later future periods. For some variables (mean temperature, temperature extremes), the choice of emission scenario becomes more critical than model uncertainty for the second part of the 21st century (Tebaldi et al., 2006; Hawkins and Sutton, 2009, 2011) 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. Users need to be aware of such issues in deciding the range of uncertainties that it is appropriate to consider for their particular risk or impacts assessment

In summary, confidence in climate change projections depends on the considered (temporal and spatial) scale, variable and whether one considers extremes or mean quantities. Confidence is highest for temperature, especially on global scales, and decreases when other variables are considered, and when we focus on smaller spatial domains (Tables 3.1 and 3.3.). Confidence in projections for extremes is weaker than for projections of long-term averages.

END BOX 3.1 HERE

[INSERT TABLE 3.3 HERE
Table 3.3: Projected regional changes in temperature and precipitation (including dryness) extremes. See Figure 3.2 for definitions of regions. Projections are for the end of the 21st century vs end of the 20th century (i.e., 1961-1990 or 1980-1999 vs 2071-2100 or 2080-2099) and for the A2/A1B emissions scenario. Codes for the source of modelling evidence: G: Based on GCM simulations. **G**: multi-GCM. R: Based on RCM simulations. **R**: multi-GCM. R: multi-RCM. T06 stands for Tebaldi et al. (2006), SW08 stands for Sheffield and Wood (2008b), and OS11 stands for Orlowsky and Seneviratne (2011).]

3.3. Observed and Projected Changes of Weather and Climate Extremes

3.3.1. Temperature

Temperature is associated with several types of extremes, e.g., heatwaves and cold spells, and related impacts, e.g., on human health, ecosystems, and energy consumption (Chapter 4). Temperature extremes often occur on weather timescales which require daily or higher timescale resolution data to accurately assess possible changes (Section 3.2.1). It is important to distinguish between daily mean, maximum (i.e., daytime), and minimum (nighttime) temperature, as well as between cold and warm extremes, due to their differing impacts. Spell lengths (e.g., duration of heatwaves) are relevant for a number of impacts. Note that we do not consider here changes in diurnal temperature range or frost days, which are not typical "climate extremes". There is an extensive body of literature, regarding the mechanisms of changes in temperature extremes (e.g., Christensen et al., 2007; Meehl et al., 2007b; Trenberth et al., 2007). Heatwaves 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 (in transitional climate regions), whereby the latter can act as an amplifying mechanism through reduction in evaporative cooling in (Section 3.1.4), but also induce enhanced persistence due to soil moisture memory (Lorenz et al., 2010). Also snow feedbacks (Section 3.1.4) and changes in aerosols (Portmann et al., 2009) are relevant for temperature extremes. In the context of global warming enhanced temperatures, including temperature extremes, are induced by enhanced greenhouse forcing, also independently of changes in circulation patterns or surface feedbacks.

Regional historical or paleoclimatic temperature reconstructions can help place the recent instrumentally observed temperature extremes in the context of a much longer period, but literature on this topic is very sparse. For example Dobrovolny et al. (2010) reconstructed monthly and seasonal temperature over central Europe back to 1500 using a variety of temperature proxy records. They concluded that only two recent temperature extremes, the summer 2003 heatwave and the July 2006 heatwave exceed the +2 standard deviation (associated with the reconstruction method) of previous monthly temperature extremes since 1500. The coldest periods within the last five centuries occurred in the winter and spring of 1690. Another 500-year temperature reconstruction was recently completed for the Mediterranean basin by means of documentary data and instrumental observations (Camuffo et al., 2010). It suggests strong natural variability in the basin, possibly exceeding the recent warming, although discontinuities in the records limits the interpretation of this finding.

The IPCC AR4 (Trenberth et al., 2007) reported based on the CRU/UKMO datatset (Brohan et al., 2006) that global mean surface temperatures rose by 0.74°C ±0.18°C over the 100-year period 1906–2005, with a rate of warming over the 50-year period 1956–2005 almost double that over the last 100 years (0.13°C± 0.03°C vs. 0.07°C ± 0.02°C per decade). It further reported that trends were found to be stronger over land than over the oceans, and that for the globe as a whole, surface air temperatures over land rose at about double the ocean rate after 1979, with the greatest warming during winter (December to February) and spring (March to May) in the Northern Hemisphere. The AR4 also noted that the changes have not been linear and can be characterized as level prior to about 1915, a warming to about 1945, leveling out or even a slight decrease until the 1970s, and a fairly linear upward trend since then (Trenberth et al., 2007). It has been suggested that the partial levelling out and/or decrease in some regions from ca. 1945 until the end of the 1970s (and in some regions until the mid-1980s) is due to a so called "dimming" of incoming shortwave radiation in several regions, followed upon by a "brightening" phase, both linked with changes in aerosol concentrations and/or cloud cover (Pinker et al., 2005; Wild et al., 2005; Wild, 2009).

Consistent with this warming in mean temperatures, the AR4 (Trenberth et al., 2007, based on Alexander et al., 2006) reported a statistically significant increase in the numbers of warm nights and a statistically significant reduction in the numbers of cold nights for 70-75% of the land regions with data (for the spatial coverage of this dataset and the definition of warm/cold days and nights, see Section 3.2.1). Changes in the numbers of warm days and cold days also showed warming, but less marked than for nights, with ca. 40-50% of the area with data showing statistically significant changes consistent with warming (Alexander et al., 2006). Less than 1% of the area with data showed statistically significant trends in cold/warm days and nights that were consistent with cooling (Alexander et al., 2006). Trenberth et al. (2007) also reported, based on Vose et al. (2005), that 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, and that for 1979 to 2004, the corresponding linear trends for the land areas with data were 0.29°C per decade for both maximum and minimum temperature. Based on this evidence, the IPCC AR4 (IPCC, 2007b) assessed that it was *very likely* that there had been trends towards warmer and more frequent warm days and warm nights, and towards warmer and less frequent cold days and cold nights in most land areas.

Regions which were found to depart from this overall behaviour towards more warm extremes and less cold extremes in Alexander et al. (2006) were mostly Central North America, the Eastern U.S., Southern Greenland (increase in cold days and decreases in warm days), and the southern half of South America (decrease in warm days; no data available for northern half of continent). In Central North America and the Eastern U.S. this partial tendency for a cooling trend in extremes is also consistent with a reported mean negative trend in temperatures, mostly in the spring to summer season (also termed "warming hole", e.g., Pan et al., 2004; Portmann et al., 2009). Several explanations have been suggested for this behaviour, which seems partly associated with a change in the hydrological cycle, possibly linked to soil moisture and/or aerosol feedbacks (Pan et al., 2004; Portmann et al., 2009).

More recent analyses available since the AR4 include a global study (for annual extremes) by Brown et al. (2008) based on the dataset from Caesar et al. (2006), and regional studies for North America (Peterson et al., 2008a; Meehl et al., 2009b), Central-Western Europe (since 1880; Della-Marta et al., 2007a), central and eastern Europe (Bartholy and Pongracz, 2007; Kurbis et al., 2009), the eastern Mediterranean including Turkey (Kuglitsch et al., 2010), western Central Africa, Guinea Conakry and Zimbabwe (Aguilar et al., 2009), the Tibetan Plateau (You et al., 2008) and China (You et al., 2011), Uruguay (Rusticucci and Renom, 2008), and Australia (Alexander and Arblaster, 2009). Further references can also be found in Table 3.2. Overall, these studies are consistent with the assessment of an increase in unusually warm nights and days and a reduction in unusually cold nights and days on the global basis, although they do not necessarily consider trends in all four variables, and a few single studies present statistically not significant or opposite trends to the global tendencies in some extremes, subregions, seasons, or decades. For instance, (Rusticucci and Renom, 2008) found in Uruguay a reduction of cold nights, a positive but a statistically not significant trend in warm nights, statistically not significant decreases in cold days at most investigated stations, and inconsistent trends in warm days. Together with the previous results from Alexander et al. (2006) for southern South America (see above) and further regional studies (Table 3.2), this suggests a less consistent warming tendency in South America compared to other continents. Another notable feature is that studies for Central and Southern Eastern Europe display a marked change point in trends in temperature extremes at the end of the 1970s / beginning of 1980s (Table 3.2), which for some extremes can lead to very small and/or statistically not significant overall trends since the 1960s (e.g., Bartholy and Pongracz, 2007). The timing of the change point is consistent with evidence from global trends in mean temperature (above) and may be linked to changes in incoming radiation (dimming/brightening, see above).

There are fewer studies available investigating changes in heatwave characteristics, rather than intensity or frequency of warm days or nights. Alexander et al. (2006) provided an analysis of trends in warm spells mostly in the mid- and high latitudes of the northern hemisphere. The analysis display a tendency towards longer warm spells in much of the region, with the exception of the Southeastern U.S. and Eastern Canada. Regional studies on trends in heatwaves are listed in Table 3.2. Kunkel et al. (2008) found that the U.S. has experienced a strong increase in heatwaves since 1960, although the heatwaves of the 1930s associated with extreme drought conditions still dominate the 1895-2005 time series. Kuglitsch et al. (2009) reported an increase in heatwave intensity, number and length in summer over the 1960-2006 time period in the Eastern Mediterranean. Ding et al. (2010) reported increasing numbers of heatwaves over most of China for the 1961-2007 period. The record-breaking heatwave over western and central Europe in the summer of 2003 is an example of an exceptional recent extreme (Beniston, 2004; Schär 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 perhaps the hottest since at least 1500 (Luterbacher et al., 2004). Other examples of recent extreme heatwaves include the 2006 heatwave in Europe (Rebetez et al., 2008), the 2007 heatwave in Southeastern Europe (Founda and Giannakopoulos, 2009), the 2009 heatwave in southeastern Australia (National Climate Centre), and the 2010 heatwave in Russia. Both the 2003 European heatwave (Andersen et al., 2005; Ciais et al., 2005) and the 2009 southeastern Australian heatwave were also associated with drought conditions, which can strongly enhance temperature extremes during heatwaves (see also Section 3.1.4).

Some recent analyses have led to some revisions of previously reported trends. For instance, Della-Marta et al. (2007a) found that mean summer maximum temperature change over Europe was +1.6±0.4°C, a somewhat stronger increase than reported in earlier studies. Kuglitsch et al. (2009; 2010) homogenised and analysed over 250 daily maximum and minimum temperature series in the Mediterranean region since 1960, and found that after homogenisation the positive trends in the frequency of hot days and heatwaves in the Eastern Mediterranean were higher than reported in earlier studies. This was due to the correction of many warm biased temperature records in the region during the 1960s and 1970s.

In summary, regional and global analyses of temperature extremes on land generally show recent changes consistent with a warming climate on the global scale, in agreement with the previous assessment from AR4. Only a few regions show changes in temperature extremes consistent with cooling, most notably for some extremes in Central North America, the Eastern U.S., and also parts of South America. Based on the available evidence we can state that it is *very likely* that there has been an overall decrease in the number of unusually cold days and nights and *very likely* that there has been an overall increase in the number of unusually warm days and nights *on the global scale*, i.e., for land areas with data (corresponding to ca. 70-80% of all land areas, see Table 3.2). It is *likely* that this statement applies at the continental scale in North America and Europe, and *very likely* that it applies in Australia (Table 3.2). However, some subregions on these continents have had warming trends in temperature extremes that were small or not statistically significant (e.g., Southeastern Europe), and a few subregions have had cooling trends in some temperature extremes (e.g., Central North America and Eastern U.S.). Asia also shows trends consistent with warming in most of the continent, but which are assessed here to be of *medium confidence* because of lack of literature for several regions beside the global study from Alexander et al. (2006). Most of Africa is insufficiently well sampled to allow an overall likelihood statement to be made at the continental scale, although most of the regions on this continent for which data are available have exhibited warming in temperature extremes (Table 3.2). In South America, both lack of data, and partial inconsistencies in the reported trends imply *low confidence* in the overall trends at the continental scale (Table 3.2). Furthermore, based on a limited number of regional analyses and implicit from the documented changes in daily temperatures, it appears that warm spells, including heatwaves defined in various ways, have *likely* increased in frequency since the middle of the 20th century in many regions with some exceptions (Table 3.2).

The AR4 (Hegerl et al., 2007) concluded that surface temperature extremes have *likely* been affected by anthropogenic forcing. This assessment was based on multiple lines of evidence of temperature extremes at the global scale including the reported increase in the number of warm extremes and decrease in the number of cold extremes on that scale (Alexander et al., 2006). There was also evidence that anthropogenic forcing may have statistically significantly increased the likelihood of extreme temperatures (Christidis et al., 2005) and of the 2003 European heat wave (Stott et al., 2004).

Recent studies on attributions of changes in temperature extremes have tended to reaffirm the conclusions reached in the AR4. Alexander and Arblaster (2009) found that trends in 'warm nights' over Australia could only be reproduced by a coupled model that included anthropogenic forcings. 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. can be attributed 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 heatwave 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 heatwave 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. (2011) 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 probability distributions (Section 3.1.2) to the observed extreme temperatures with a time-evolving pattern of location parameters as obtained from the model simulation, and found that both anthropogenic influence and combined influence of anthropogenic and natural forcing can be detected in all four 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 at global and regional scales. Globally, waiting times for events that were expected to recur 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 3.3). However, the available detection and attribution studies for extreme maximum temperatures (Christidis et al., 2011; Zwiers et al., 2011) suggest that the models over-estimate changes in these extremes during the late 20th century.

[INSERT FIGURE 3.3 HERE
Figure 3.3: 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. (2011). 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.]

Regarding projections of extreme temperatures, the AR4 (Meehl et al., 2007b) noted that cold episodes were projected to decrease significantly in a future warmer climate and considered *very likely* that heatwaves would be more intense, more frequent and last longer in a future warmer climate. Post-AR4 studies of temperature extremes have utilised larger model ensembles (Kharin et al., 2007; Sterl et al., 2008; Orlowsky and Seneviratne, 2011) and generally confirm the conclusions of AR4, while also providing more specific assessments both in terms of the range of considered extremes and the level of regional detail (see also Table 3.3).

There are few *global* analyses of multi-model projections in temperature extremes available in the literature. The study by Tebaldi et al. (2006), which was referenced in the AR4 (Figures. 10.18 and 10.19 in Meehl et al., 2007b), provided global analyses of projected changes (A1B scenario) in several extremes based on 9 GCMs. For temperature extremes, analyses were provided for heatwave lengths (using the HWDImax index, see Section 3.1.2 and discussion) and warm nights. Stippling was provided when 5 out of 9 models displayed statistically significant changes of the same sign. Orlowsky and Seneviratne (2011) recently updated the analysis from Tebaldi et al. (2006) for the full ensemble of GCMs (23 in total) that contributed A2 scenarios to the CMIP3, using a larger number of extreme indices (for temperature; HWDImean and WSDI in addition to HWDImax, see Section 3.1.2; and percentages of warm days, cold days, warm nights, cold nights, days with temperature greater than 30°C and nights with temperatures greater than 20°C), using other thresholds for display and stippling of the figures (no results displayed if less than 66% of the models agree on the sign of change, stippling provided only for 90% model agreement), and providing seasonal analyses. This analysis confirmed that strong agreement exists between the various GCM projections for temperature-related extremes, with projected increases of warm day occurrences (Figure 3.4) and heatwave length (see discussion in Section 3.1.2), and decreases of cold extremes (Figure 3.5). Moderate temperature extremes on land were found to be projected to warm faster than global annual mean temperature in many regions and seasons (Figure 3.1), implying large changes in extremes in some places, even for a global warming of 2°C or 3°C (with scaling factors for the SRES A2 scenario ranging between 0.5 and 2.5 for moderate seasonal extremes, Figure 3.1). Based on the analyses of Tebaldi et al. (2006) and Orlowsky and Seneviratne (2011), as well as physical considerations, we assess that increases in the number of hot extremes and decreases in the number of cold extremes (defined with respect to present regional climate, i.e., 1961-1990 reference period) are *virtually certain* on the global scale. Further, given the assessed changes in hot and cold extremes and available analyses of projected changes in heatwave length in the two studies, we assess that it is *very likely* that the length, frequency and/or intensity of heatwaves will increase on the global scale.

Another global study of changes in extremes based on the CMIP3-ensemble is provided in Kharin et al. (2007), which focuses on changes in annual extremes (20-year extreme values) based on 14 GCMs for temperature extremes and 16 GCMs for precipitation extremes and employed the SRES A2, A1B, and B1 emissions scenarios. This analysis projects increases in the temperature of the one-in-twenty years annual extreme hottest day of 2-6°C (depending on region; Figure 3.6 adapted from Kharin et al., 2007) , and strong reductions in the waiting times of this extreme event. However, as noted above, the limited number of relevant detection and attribution studies suggest that models may over-estimate the changes in temperature extremes, and our assessments take this into account by weakening the uncertainty assessments from what would be derived by uncritical acceptance of the projections in Figure 3.6. The uncertainty estimates are also reduced to reflect the possibility that some important processes relevant to extremes may be missing or be poorly represented in models, as well as the fact that the model projections considered in this study did not correspond to the full CMIP3 ensemble. Globally we assess that under the A2 and A1B scenarios a one-in 20 year annual extreme hot day is *likely* to become a one-in-two year annual extreme by the end of the 21st century in most regions, except in the high latitudes of the northern hemisphere where it is *likely* to become a one-in-five year annual extreme (Figure 3.6b, newly computed based on material from Kharin et al., 2007). Further, we assess that under the more moderate B1 scenario a current one-in-20 year extreme would *likely* become a one-in-five year event (and a one-in-ten year event in northern hemisphere high latitudes).

In the following paragraph, regional assessments of projected changes in temperature extremes are provided. More details are found in Table 3.3. For North America, the U.S. Climate Change Science Program (CCSP) reached the following conclusions (using IPCC likelihood terminology) regarding projected changes in temperature extremes by the end of the 21st century (Gutowski et al., 2008a): 1) Abnormally hot days and nights and heat waves are *very likely* to become more frequent; 2) Cold days and cold nights are *very likely* to become much less frequent; 3) 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. For Australia, the CMIP-3 ensemble was projected 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). For the entire South American region, a study with a single RCM projected more frequent warm nights and fewer cold nights (Marengo et al., 2009a). Several studies of regional and global projections of changes in extremes are available for the European continent (see also Table 3.3.). 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 distribution for 2007 lies entirely within the distribution for 2071–2100 - thus 2007 might be considered a ‘normal’ summer of the future (Founda and Giannakopoulos, 2009; Tolika et al., 2009). Beniston et al. (2007) concluded from an analysis of RCM output that regions such as France and Hungary, may experience as many days per year above 30°C as currently experienced in Spain and Sicily. In this RCM ensemble, France was the area with the largest projected 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 heatwaves, especially in southern Europe (Fischer and Schär, 2010). Overall these regional assessments are consistent with the global assessments provided above.

[INSERT FIGURE 3.4 HERE

Figure 3.4: Projected annual and seasonal changes of three indices for Tmax: Fraction of warm days, fraction of cold days, and fraction of days with Tmax > 30°C; CMIP3 projections, 2080-2100 time frame minus 1980-2000 time frame

(projections for A2 scenario, relative to late 20th century (20C3M) simulations), annual (top), DJF (middle) and JJA (bottom). Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].

[INSERT FIGURE 3.5 HERE
Figure 3.5: Projected annual and seasonal changes of three indices for Tmin: Fraction of warm nights, fraction of cold nights, and fraction of days with Tmin > 20°C; CMIP3 simulations, 2080-2100 time frame minus 1980-2000 time frame (projections for A2 scenario, relative to late 20th century (20C3M) simulations), annual (top), DJF (middle) and JJA (bottom). Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].

[INSERT FIGURE 3.6 HERE
Figure 3.6: (a, top) Projected changes from the late-twentieth-century 20-year return values of annual maximum of the daily maximum temperature in the mid-21st century (left) and in late-21st century (right) by 14 GCMs that contributed to the CMIP3, under three different SRES emission scenarios B1 (blue), A1B (green) and A2 (red); units in °C. Adapted from the analysis in Kharin et al. (2007). The vertical extent of the whiskers shows the range of projected changes from 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). Model projections suggest that the the 20-year extreme annual daily maximum temperature will increase by about 2°C by mid-21st century and by about 4°C by late-21st century, depending on the region.
(b, bottom) Projected waiting times for late-twentieth-century 20-year return values of annual maximum of the daily maximum temperature in the mid-21st century (left) and in late-21st century (right) by 14 GCMs that contributed to the CMIP3, under three different SRES emission scenarios B1, A1B and A2 Adapted from the analysis in Kharin et al. (2007). The vertical extent of the whiskers shows the range of projected changes from 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). Model projections suggest that the waiting time for a late 20th century 20-year extreme annual daily maximum temperature will be reduced to about 2-20 years by mid-21st century and by about 1-5 years by late-21st century, depending on the region. Two global domains for which projections are shown are: the entire globe including the oceans, and the global land areas.]

Temperature extremes were the type of extremes projected to change with most confidence in the AR4 (IPCC, 2007a). This is confirmed regarding the sign of change with more recent analyses (Figure 3.4 and 3.5, from Orlowsky and Seneviratne, 2011), although there is a large spread with respect to the magnitude of changes both due to emission scenario and climate model uncertainty (Figures 3.6a and 3.6b, adapted from Kharin et al., 2007). If changes in temperature extremes scale with changes in mean temperature (i.e., simple shifts of the probability distribution), 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 1961-1990 climate). Changes in the tails of the temperature distributions may not scale with changes in the mean in some regions (Section 3.1.6), though in most such reported cases hot (cold) extremes tend to increase (decrease) more than mean temperature, and thus the above statement for extremes (*virtually certain* increase in hot extremes and decrease in cold extremes) still applies. Central and Eastern Europe is a region where evidence suggests that projected changes in temperature extremes result from both changes in the mean as well as from changes in the shape of the probability distributions (Schär et al., 2004). The main mechanism for the widening of the distribution is linked to the drying of the soil in this region (Sections 3.1.4 and 3.1.6). Furthermore, remote surface heating may induce circulation changes that modify the temperature distribution (Haarsma et al., 2009). Other local, mesoscale and regional feedback mechanisms, in particular with land surface conditions (beside soil moisture, also with vegetation and snow; Section 3.1.4) and aerosol concentrations (Ruckstuhl and Norris, 2009) may enhance the uncertainties in temperature projections. Some of these processes occur on a small scale un-resolved by the models (Section 3.2.3). In addition, lack of observational data (e.g., for soil moisture and snow cover, see Section 3.2.1) reduces the possibilities to validate 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 heatwaves 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).

In summary, since 1950 it is *very likely* that there has been an overall decrease in the number of unusually cold days and nights and an overall increase in the number of unusually warm days and nights on the global scale, i.e., for land areas with data. It is *likely* that such changes have also occurred at the continental scale in North America and Europe, and *very likely* in Australia. There is *medium confidence* of a warming trend in temperature extremes in much of Asia. There is *low confidence* in trends for Africa, because of lack of data and

studies. In South America, lack of data, and some inconsistencies between reported trends imply *low confidence* in the trends at the continental scale. It is *likely* that the number of warm spells, including heatwaves, have increased since the middle of the 20th century in many (but not all) regions. On the global scale, climate change projections indicate a *virtually certain* increase in the number of hot extremes and *virtually certain* decrease in the number of cold extremes (defined with respect to present regional climate, i.e., 1961-1990 reference period). This is mostly linked with mean changes in temperatures, although changes in temperature variability can play an important role in some regions. It is *very likely* that the length, frequency and/or intensity of heatwaves (defined with respect to present regional climate) will continue to increase on the global scale. Projected changes on sub-continental scales are less certain than is the case for the global scale. A one-in-20 year annual hottest day is *likely* to become a one-in-two year annual extreme by the end of the 21st century in most regions, except in the high latitudes of the northern hemisphere where it is *likely* to become a one-in-five year annual extreme. Moderate temperature extremes on land are projected to warm faster than global annual mean temperature in many regions and seasons. A mean global warming of 2°C or 3°C is *likely* to lead to much larger increases in some temperature extremes in certain regions and seasons (with scaling factors for the SRES A2 scenario *likely* ranging between 0.5 and 2.5 for moderate seasonal extremes). Nevertheless, mean global warming does not necessarily imply warming in all regions and seasons.

3.3.2. Precipitation

This section addresses changes in short-term extreme or heavy precipitation events. Changes in mean (or total) precipitation that can lead to drought (i.e., associated with lack of precipitation) are considered in Section 3.5.1. Because climates are so diverse across different parts of the world, it is difficult to provide a single definition of extreme or heavy precipitation. In general, two different approaches have been used: 1) relative thresholds such as percentiles and return values (typically the 95th percentile) and 2) absolute thresholds (e.g., 50.8 mm (2 inches)/day of rain in the U.S., and 50mm/day or 100mm/day of rain in China). For more details on the respective drawbacks and advantages of these two approaches, see Section 3.1. Note that we do not distinguish between rain and snowfall (both considered as contributors to overall extreme precipitation events), but do distinguish changes in hail from other precipitation types. Increases in public awareness and changes in reporting practices have led 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). Furthermore, weather events such as hail are not well captured by current monitoring systems and, in some parts of the world, the monitoring network is very sparse (Section 3.2.1), resulting in considerable uncertainty in the estimates of extreme precipitation. There are also known biases in precipitation measurements, mostly leading to rain undercatch.

Little evidence of paleo and historical changes in heavy precipitation is available to place recent variations into context. An overview of mid- to late-Holocene climate change (Wanner et al., 2008) suggested a pronounced weakening of the monsoon systems in Africa and Asia and increasing dryness and desertification on both continents, which accompanied a progressive southward shift of the Northern Hemisphere summer position of the Intertropical Convergence Zone. A study for Europe (Pauling and Paeth, 2007) suggested that there were large fluctuations in wet winters over the last 300 years, and that 1951-2000 displays more extreme wet winters than other 50-year periods in the 300 preceding years with the exception of 1701-1750. A study for the Middle East (Black et al., 2010) reported decreased winter rainfall in southern Europe and the Middle East and increased rainfall further north during the Holocene, caused by a poleward shift of the North Atlantic storm track and a weakening of the Mediterranean storm track. A study for southern Spain (Rodrigo et al., 1999) suggested that the wettest periods occurred at the end of 16th century, the beginning of 17th century, and at the end of 19th century, while the driest periods in the pre-instrumental era occurred during the first half of the 16th century, and around 1750.

The AR4 (Trenberth et al., 2007) concluded that it was *likely* that there had been increases in the number of heavy precipitation events (e.g., 95th percentile) within many land regions, even in those where there had been a reduction in total precipitation amount, consistent with a warming climate and observed significant increasing amounts of water vapour in the atmosphere. Increases had also been reported for rarer precipitation events (1 in 50 year return period), but only a few regions had sufficient data to assess such trends reliably. However, the AR4 (Trenberth et al., 2007) also stated that "Many analyses indicate that the evolution of rainfall statistics through the second half of the 20th century is dominated by variations on the interannual to inter-decadal time scale and that trend estimates are spatially incoherent (Manton et al., 2001; Peterson et al., 2002; Griffiths et al., 2003; Herath and Ratnayake, 2004)". Overall, as highlighted in Alexander et al. (2006), the observed changes in precipitation extremes were found at the time to be much less spatially coherent and statistically significant compared to observed changes in temperature extremes: Although statistically significant trends towards stronger precipitation extremes were generally found for a larger fraction of the land area than trends towards weaker precipitation extremes, statistically significant changes in precipitation indices for the overall land areas with data were only found for precipitation intensity, and not for other considered indices (Alexander et al., 2006).

Post-AR4 studies updated the results assessed at that time, with more regions being covered (Table 3.2). Overall, this additional evidence confirms that more locations and studies show an increase than a decrease in extreme precipitation, but that there are also wide regional and seasonal variations, and that trends in many regions are not statistically significant (Table 3.2). More detailed regional assessments are provided hereafter.

Recent studies on past and current changes of 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), have reported an increasing trend over the last half century. Based on station data from Canada, the U.S., and Mexico, Peterson et al. (2008b) reported 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) showed a 20% reduction in the return period for extreme precipitation of different return levels over 1950–2007; Gleason et al. (2008) reported an increasing trend in the area experiencing a much above-normal proportion of heavy daily precipitation from 1950 to 2006; Pryor et al. (2009) provided 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) were focused on the central plains/northwestern Midwest (Pryor et al., 2009). In the core of the North American monsoon region in northwest Mexico, statistically 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. However, no statistically significant changes were found in coastal stations (Cavazos et al., 2008). Overall, the evidence indicates a *likely* increase in observed heavy precipitation in many regions in North America, despite statistically non-significant trends and some decreases in some subregions (Table 3.2).

There is overall *low confidence* in trends for the whole of Central and South America (Table 3.2). Positive trends in extreme rainfall events are evident in parts of southern South America (Dufek and Ambrizzi, 2008; Marengo et al., 2009b; Re and Ricardo Barros, 2009; Sugahara et al., 2009). But negative trends have been observed in winter extreme precipitation in some regions (Penalba and Robeldo, 2010).

There is *medium confidence* in trends in heavy precipitation in Europe, due to partly inconsistent signals across studies and regions, especially in summer (Table 3.2). Winter extreme precipitation has increased in part of the continent, in particular in Central-Western Europe and European Russia (Zolina et al., 2009), but the trend in summer precipitation has been weak or not spatially coherent (Moberg et al., 2006; Bartholy and Pongracz, 2007; Maraun et al., 2008; Pavan et al., 2008; Zolina et al., 2008; Costa and Soares, 2009; Kysely, 2009; Durão et al., 2010; Rodda et al., 2010). Increasing trends in 90th, 95th and 98th percentiles of daily winter precipitation over 1901–2000 were found (Moberg et al., 2006), which has been confirmed by more detailed country-based studies for the United Kingdom (Maraun et al., 2008), Germany (Zolina et al., 2008), Belgium (Ntegeka and Willems, 2008), Central and Eastern Europe (Bartholy and Pongracz, 2007; Kysely, 2009), while decreasing trends have been found in some regions such as northern Italy (Pavan et al., 2008), Poland (Lupikasza, 2010) and some Mediterranean coastal sites (Toreti et al., 2010). Uncertainties are overall larger in Southern Europe and the Mediterranean, where there is *low confidence* in the trends (Table 3.2). A recent study (Zolina et al., 2010) has indicated that there has been an increase by about 15-20% in the persistence of wet spells over most of Europe over the last 60 years, which was not caused by an increase of the total number of wet days.

There is overall *low confidence* in trends in heavy precipitation in Asia, both on the continental and regional scale for most regions (Table 3.2; see also Alexander et al., 2006). In the Asia-Pacific region, no systematic spatially coherent trends in the frequency and duration of extreme precipitation events have been found (Choi et al., 2009). However, statistically significant positive and negative trends were observed at sub-regional scales within this region. Heavy precipitation increased in Japan during 1901-2004 (Fujibe et al., 2006), and in India (Rajeevan et al., 2008; Krishnamurthy et al., 2009) especially during the monsoon seasons (Sen Roy, 2009; Pattanaik and Rajeevan, 2010). Both statistically significant increases and decreases in extreme precipitation have been found in China over the period 1951-2000 (Zhai et al., 2005) and 1978-2002 (Yao et al., 2008). Heavy precipitation increased over the southern and northern Tibetan Plateau but decreased in the central Tibetan Plateau during 1961–2005 (You et al., 2008). No spatially coherent trends in extreme precipitation during 1950-2003 over mid-East countries were found (Zhang et al., 2006). In Peninsular Malaysia during 1971–2005 the intensity of extreme precipitation increased and frequency decreased, while the trend in the proportion of extreme rainfall over total precipitation was not statistically significant (Zin et al., 2009).

In Southern Australia, there has been a *likely* increase in heavy precipitation in many areas, except where mean precipitation has decreased (Table 3.2), but there is *low confidence* in the trends in Northern Australia due to lack of literature (Table 3.2). 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 (Aryal et al., 2009).

There is *low to medium confidence* in regional trends in heavy precipitation in Africa due to partial lack of literature and data, and due to lack of consistency in reported patterns in some regions (Table 3.2). The IPCC AR4 (Trenberth et al.,

2007) reported an increase in heavy precipitation over southern Africa, but this appears to depend on region and precipitation index examined (Kruger, 2006; New et al., 2006; Seleshi and Camberlin, 2006; Aguilar et al., 2009; Camberlin et al., 2009). Central Africa exhibited a decrease in heavy precipitation over the last half century (Aguilar et al., 2009), however data coverage for large parts of the region was poor. The IPCC AR4 reported a decrease in heavy precipitation in east Africa, but Camberlin et al., (2009) found no trend in daily precipitation intensity. There were decreasing trends in heavy precipitation over parts of Ethiopia over the period 1965-2002 (Seleshi and Camberlin, 2006).

Changes in hail occurrence are generally difficult to quantify because hail occurrence is not well captured by the monitoring system. Sometimes, changes in the environment conditions conducive to hail occurrence are used to infer changes in hail occurrence. However, the atmospheric conditions are typically estimated from reanalyses or from radiosonde data that are associated with high uncertainty. As a result, assessment of changes in hail frequency is difficult. Over the United States, DeRubertis (2006) found widespread trends toward enhanced atmospheric instability in summer and Changnon and Changnon (2000) found five types of temporal variations of hail frequency. For severe thunderstorms in the region east of the Rocky Mountains in the United States, Brooks and Dotzek (2008) found strong variability but no clear trend in the past 50 years. Cao (2008) identified a robust upward trend in hail frequency over Ontario, Canada. Kunz et al. (2009) found that both hail damage days and convective instability increased during 1974-2003 in a state in southwest Germany. Piani et al. (2010) identified an increasing trend in hailstorm frequency in Italy during 1961-2003. Xie et al. (2008) identified no trend in the mean annual hail days in China from 1960 to early 1980s but a statistically significant decreasing trend afterwards.

In summary, it is *likely* that there has been statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than there has been statistically significant decreases, but there are strong regional and subregional variations in the trends. In particular, many regions present statistically non-significant or negative trends, and there are also variations between seasons (more consistent trends in winter than in summer in Europe). The overall most consistent trends towards heavier precipitation events are found in North America (*likely* increase over the whole continent). This overall assessment is consistent with that of the AR4.

The observed changes in heavy precipitation appear to be consistent with the expected response to anthropogenic forcing (increase due to enhanced moisture content in the atmosphere) 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 concluded only that it is *more likely than not* that anthropogenic influence had 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). Wang and Zhang (2008) show that winter season maximum daily precipitation in North America appears to be statistically 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 in 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 (Meehl et al., 2005) and the tropics (Emori and Brown, 2005). 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 explain why there have not been 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 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 decrease 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 expected from the Clausius-Clapeyron relationship alone (Lenderink and Van Meijgaard, 2008), though this is still under debate (Haerter and Berg, 2009; Lenderink and van Meijgaard, 2009). A comparison between observed and multi-model simulated extreme precipitation using an optimal detection method suggests that the human-induced increase in greenhouse gases has contributed to the observed intensification of heavy precipitation events over large Northern Hemispheric land areas during the latter half of the 20th century (Min et al., 2011). One study has suggested that the influence of external forcing on daily extreme precipitation at regional scales would be detectable in another decade (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).

The present assessment based on evidence from new studies and those used in AR4 is that there is a *medium confidence* 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, especially in middle and higher latitudes of the Northern Hemisphere. This does not modify the AR4 assessment (see also Section 3.1.5). 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.

Regarding projected changes in extreme precipitation, the AR4 concluded that it was *very likely* that heavy precipitation events, i.e., the frequency of heavy precipitation or proportion of total precipitation from heavy precipitation, would increase over most areas of the globe in the 21st century (IPCC, 2007a). The tendency for an increase in heavy daily precipitation events was found in many regions including some regions in which the total precipitation was projected to decrease.

Post-AR4 analyses of climate model simulations partly confirm this assessment but also highlight fairly large uncertainties and model biases in projections of changes in heavy precipitation in some regions (Section 3.2.3 and Table 3.3). On the other hand, more GCM and RCM ensembles have now been analysed for some regions, leading to increased robustness of the projected changes (Table 3.3; see also e.g., Kharin et al., 2007; Kim et al., 2010; Hirschi et al., 2011). At the time of the AR4, Tebaldi et al. (2006) was the main global study available on projected changes in precipitation extremes (e.g., Figure 10.18 of Meehl et al., 2007b). Orlowsky and Seneviratne (2011) extended this analysis to a larger number of GCMs from the CMIP3 ensemble (see also Section 3.3.1). Figure 3.7 provides corresponding analyses of projected annual and seasonal changes of the wet-day intensity, the fraction of days with precipitation above the 95%-quantile of daily wet-day precipitation, and the fraction of days with precipitation above 10 mm/day. It should be noted that the 10 mm/day threshold cannot be considered extreme in several regions, but highlights differences in projections for absolute and relative thresholds (see also discussion in Section 3.1.2 and beginning of this section). All three indices were also considered in Tebaldi et al. (2006). Figure 3.7 indicates that regions with model agreement (at least 66%) with respect to changes in heavy precipitation are mostly found in the high latitudes and in the tropics, and in some mid-latitude regions of the Northern Hemisphere in the boreal winter. Regions with at least 90% model agreement are even more limited and confined to the high latitudes. Overall, model agreement in projected changes is found to be stronger in boreal winter (DJF) than summer (JJA) for most regions. Kharin et al. (2007) analyzed changes in annual maxima of 24-hour precipitation in the outputs of 14 CMIP3 simulations. Figure 3.8a displays the projected percentage change in annual maximum of 24-hour precipitation rate from the late-20th century 20-year return values, while Figure 3.8b displays the corresponding projected waiting times for late-20th-century 20-year return values of annual maximum 24-hour precipitation rates in the mid-21st century (left) and in late-21st century (right) under three different emission scenarios SRES B1, A1B and A2. Between the late 20th and the late 21st century, the projected responses of extreme precipitation to future emissions show increased precipitation rates in most regions, and decreases in waiting times in most regions in the high latitudes and the tropics and in some regions in the mid-latitudes (consistent with projected changes in heavy precipitation, see Figure 3.7 and Tebaldi et al., 2006), although there are increases in waiting times or only small changes projected in several regions (mostly in the southern half of South America, Central America, Central North America, Southern Asia, and Northern Australia). Except for these regions, the waiting period for an event of annual maximum 24-hour precipitation with a 20-year return period in the late-20th-century is projected to be about 5-15 years by the end of the 21st century. The greatest projected reductions in waiting time are in high latitudes and some tropical regions. The more extreme emissions scenarios (A1B and A2) lead to stronger projected decreases in waiting time.

[INSERT FIGURES 3.7 HERE

Figure 3.7: Projected annual and seasonal changes of three precipitation indices: Wet day intensity, fraction of days with precipitation above the 95%-quantile of daily wet day precipitation and fraction of days with pr > 10mm; CMIP3 simulations, 2080-2100 time frame minus 1980-2000 time frame (projections for A2 scenario, relative to late 20th century (20C3M) simulations), annual (top), DJF (middle) and JJA (bottom). Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].]

[INSERT FIGURES 3.8 HERE

Figure 3.8:

(a, top) Projected changes from the late-20th-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 CMIP3, under three different SRES emission scenarios B1 (blue), A1B (green) and A2 (red) (adapted from Kharin et al., 2007).

The vertical extent of the whiskers shows the range of projected changes from 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 projected change in extreme precipitation is large, the median model projection is that the extreme 24-hour precipitation rate will increase by about 5-10% by mid-21st century and by about 10-20% by late-21st century, depending on the region and the emissions scenario.
(b, bottom) 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 CMIP3, under three different emission scenarios SRES B1 (blue), A1B (green) and A2 (red) (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 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. Two global domains for which projections are shown are: the entire globe including the oceans, and the global land areas.]

Future precipitation projected by the CMIP3 models has also been analyzed in a number of studies for various regions using different combinations of the models (Table 3.3 and next paragraphs). In general these studies confirm the findings of global-scale studies by Tebaldi et al. (2006), Kharin et al. (2007) and Orlowsky and Seneviratne (2011).

By analyzing simulations with a single GCM, Khon et al. (2007) reported a projected general increase in extreme precipitation for the different regions in northern Eurasia especially for winter. Su et al. (2009) found that for the Yangtze River Basin region in 2001–2050, the 50-year heavy precipitation and drought events become more frequent, with return periods falling to below 25 years (relative to 1951-2000 behavior). 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). Simulations by 12 GCMs projected an increase in heavy precipitation intensity and 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 (Shongwe et al., 2009, 2011). Rocha et al. (2008) evaluated differences in the precipitation regime over southeastern Africa simulated by two GCMs under present (1961–1990) and future (2071–2100) conditions as a result of greenhouse gases anthropogenic forcing. They found that the intensity of all episode categories of precipitation events is projected to increase practically over the whole region, whereas the number of episodes is projected to decrease in most of the region and for most episode categories. Extreme precipitation is projected to increase over Australia in 2080–2099 relative to 1980–1999 in an analysis of the CMIP3 ensemble (Alexander and Arblaster, 2009). In addition, several high-spatial resolution studies are available in different regions, as highlighted in the following paragraph.

High-spatial resolution is important for studies of extreme precipitation (e.g., Kim et al., 2010). Post-AR4 studies have employed three approaches to obtain high-spatial resolution to project precipitation extremes: high-resolution GCMs, dynamical downscaling using RCMs, and statistical downscaling. Kamiguchi et al. (2006) is an example of studies that employed the first approach. With the Meteorological Research Institute and Japan Meteorological Agency (MRI-JMA) 20-km horizontal grid AGCM that was run in time slice mode, heavy precipitation was projected to increase substantially in south Asia, the Amazon, and west Africa, with increased dry spell persistence in South Africa, southern Australia, and the Amazon at the end of the 21st century. 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. Using statistical downscaling, Wang and Zhang (2008) investigated possible changes in North American extreme precipitation probability during winter from 1949–1999 to 2050–2099. Downscaled results suggested a strong increase in extreme precipitation over the south and central U.S. but decreases over the Canadian prairies. Projected European precipitation extremes in high-resolution studies tend to increase in northern Europe (Frei et al., 2006; Beniston et al., 2007; Schmidli et al., 2007), especially during winter (Haugen and Iversen, 2008; May, 2008), as also highlighted in Table 3.3. 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. Using daily statistics from various models, Boberg et al. (2009a, b) projected 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) projected positive trends in extreme quantiles of heavy precipitation over Germany, 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 project 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 Westernport region of Australia, consistent with results based on the CMIP3 ensemble (Alexander and Arblaster, 2009), and the size of this increase is greater in 2070 than in 2030 (Abbs and Rafter, 2008). When both future land use changes and increasing greenhouse-gas concentrations are considered in the simulations, tropical and northern Africa are projected to experience less extreme rainfall events by 2025 during most seasons except for autumn (Paeth and Thamm, 2007). Simulations with high resolution RCMs projected that frequency of extreme precipitation increases in the warm climate for warm or rainy season in Japan (Nakamura et al., 2008; Wakazuki et al., 2008; Kitoh et al., 2009). An increase in 90th-percentile values of daily precipitation on the Pacific side of the Japanese Islands during July in the future climate was projected with a 5-km mesh cloud-system resolving non-hydrostatic RCM (Kanada et al., 2010b).

In summary, projected changes from both global and regional studies indicate that it is *likely* that the frequency of heavy precipitation (or proportion of total rainfall from heavy falls) will increase in the 21st century over many areas in the globe, especially in the high latitudes and tropical regions, and northern mid-latitudes in winter (Table 3.3 and Figures 3.7 and 3.8). This represents a weaker (*likely* versus *very likely*) but more robust assessment than that of the AR4 (Meehl et al., 2007b), as it is based on a larger number of studies based on more numerous lines of evidence.

Post-AR4 studies indicate that the projection of precipitation extremes is associated with large uncertainties, contributed by the uncertainties related to GCMs, RCMs and statistical downscaling methods, and by the impacts of natural variability of the climate. Kysely and Beranova (2009) examined scenarios of change in extreme precipitation events in 24 future climate runs of 10 RCMs driven by two GCMs, focusing on a specific area of central Europe with complex orography. They demonstrated 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. May (2008) reported an unrealistically large projected precipitation change over the Baltic Sea in summer in the HIRHAM RCM, apparently related to an unrealistic projection of Baltic Sea warming in the driving GCM. Frei et al. (2006) found large model differences in summer when RCM formulation contributes significantly to scenario uncertainty. In exploring the ability of two statistical downscaling models in reproducing the direction of the projected changes in indices of precipitation extremes Hundecha and Bardossy (2008) 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. Themeßl et al. (2011) merged linear and nonlinear empirical-statistical downscaling techniques with bias correction methods, and demonstrated their ability to drastically reduce RCM error characteristics. 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 substantial 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 did not detect significant similarity between simulated and actual patterns for the indices of precipitation extremes in most cases. Moreover, 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. The observed amplification of rainfall extremes was larger than that predicted by models. The underestimate of rainfall extremes by the models may be related to the coarse spatial resolution used in the model simulations and suggests 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 an 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 statistically 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.

In summary, it is *likely* that there has been statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than there has been statistically significant decreases, but there are strong regional and subregional variations in the trends. There is *medium confidence* that changes in extreme precipitation at global scale may have been anthropogenically related. It is *likely* that the frequency of heavy

precipitation (or proportion of total rainfall from heavy falls) will increase in the 21st century over many areas, in particular in the high latitudes and tropical regions, and northern mid-latitudes in winter (Table 3.3 and Figures 3.7 and 3.8). Some studies also suggest increases in heavy precipitation in some regions with projected decreases of total precipitation, such as Central Europe (*medium confidence*). A one-in-20 year annual maximum 24-hour precipitation rate could *likely* become a one in 5- to 15-year event by the end of 21st century in many regions, but some regions display decreases or statistically non-significant changes in heavy precipitation based on current climate model projections.

3.3.3. Wind

Extreme wind speeds pose a threat to human safety, maritime and aviation activities and the integrity of infrastructure. As well as extreme wind speeds, other attributes of wind can cause extreme impacts. Trends in average wind speed can influence evaporation and in turn water availability and droughts (e.g., McVicar et al., 2008). 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). Aeolian processes exert significant influence on the formation and evolution of arid and semi-arid environments, being strongly linked to soil and vegetation change (Okin et al., 2006). A rapid shift in wind direction may reposition the leading edge of a forest fire (see Section 4.2.2.2, Mills, 2005) while the fire itself may generate a local circulation response such as tornadogenesis (e.g., Cunningham and Reeder, 2009). 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., 2008c), wind speed thresholds may be used to characterize the severity of the phenomenon (e.g., the Saffir-Simpson scale for tropical cyclones).

Changes in wind climate over paleo-climatic time scales were not addressed specifically in the AR4 but may be inferred from circulation changes determined from reconstructions using proxy data. Broad circulation changes have occurred across the globe from the mid-Holocene (~ 6000 years ago) to the beginning of the industrial revolution (Wanner et al., 2008). Over this period, there was a change toward a lower Northern Atlantic Oscillation (NAO) index, implying weaker westerly winds over the north Atlantic, and the ITCZ moved southward leading to weaker monsoons across Asia. The Walker Circulation strengthened, El Niño activity was higher and Southern Ocean westerlies moved northward and strengthened affecting southern Australia, New Zealand and southern South America. While the changes in the Northern Hemisphere corresponded to changes in orbital forcing, those in the Southern Hemisphere were more complex, possibly reflecting the additional role on circulation of heat transport in the ocean. Solar variability and volcanic eruptions may also have contributed to decadal to multi-centennial fluctuations over this time period (Wanner et al., 2008).

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 and concluded that mid-latitude westerlies had increased in strength in both hemispheres (Trenberth et al., 2007). Long-term high-quality wind measurements from terrestrial anemometers are sparse in many parts of the globe due to the influence of changes in instrumentation, station location, and surrounding land use (e.g., Cherry, 1988; Pryor et al., 2007; Jakob, 2011), and this has hampered the direct investigation of wind climatology changes. Nevertheless a number of recent studies have analysed mean and extreme wind speed trends from wind observations in different parts of the world. Wan et al. (2010) used a long-term (1953-2006) data series of 1-minute-mean near-surface hourly data standardised to 10 m and found decreasing trends in monthly averaged winds over western and most parts of southern Canada (except the Maritimes) in all seasons, with significant increases in the central Canadian Arctic in all seasons and in the Maritimes in spring and autumn. Over the Gulf of St Lawrence, Hundecha et al. (2008) found declining trends in annual maximum winds in the north of the gulf and increasing trends to the south in North American Regional Reanalysis (NARR) data and thirteen anemometer sites over the period 1979–2004 although the changes were mostly not statistically significant. Pryor et al. (2007) reported mostly declining trends in wind over much of the USA in 50th and 90th percentile wind speeds calculated from time series of twice daily winds at 157 sites over 1973 to 2005. Lynch et al. (2004) found statistically significant increasing trends in average winds but reported that no trends were found for the highest winds (highest daily average wind speed reported per season) in Alaska from 1955-2001. However, they note that instrument and measurement changes may have influenced their conclusions. Pirazolli and Tomasin (2003) reported a generally declining trend in both annual mean and annual maximum winds from 1951 to the mid-1970s and an increasing trend since then, based on central Mediterranean records. Over the Netherlands, Smits et al. (2005) found declining trends in winds occurring on average 10 and 2 times per year in 10-m anemometer data over 1962-2002 but increasing trends in NCEP and ERA40 reanalysis. Over China, negative trends in 10-m winds were found by Guo et al. (2011) based on winds from 652 sites over 1969-2005, and by Jiang et al. (2010a) in daily maximum wind speeds based on 535 sites over 1956–2004 and by Zhang et al. (2007b) in 2 m data at 75 sites from 1966-2003 over the Tibetan plateau, consistent with an earlier study by Xu et al. (2006) who also found declining trends in both station data and NCEP reanalyses.

Strong winds, defined by Jiang et al. (2010a) as 10 minute average exceedences or daily average exceedences of 17 m/s, and by Guo et al. (2011) as high percentiles, also declined over the period mainly during the spring and at similar rates at urban and rural sites. McVicar et al. (2008) using 2 m wind data over the 1975-2006 period reported declines in mean wind speed over 88% of Australia (significant over 57% of the country) and positive, though not necessarily significant, trends over about 12% of the mainland interior and southern and eastern coastal regions including Tasmania, whereas mostly increasing trends were found in both NCEP and ERA40 10-m winds. However, Troccoli et al. (2011) found these trends were highly sensitive to the measurement elevation, confirming the declining trend at 2 m but finding mostly increasing trends at 10 m in broad agreement with the reanalysis data over 1975-2006. In Antarctica, Turner et al. (2005) reported increasing trends in mean wind speeds over the second half of the 20th century. Consistent with many of the northern European studies, Vautard et al. (2010) found mostly declining trends across most of the continental northern mid-latitudes. Another recent study by McVicar et al. (2010) suggests, based on observations (1960-2006) from mountainous regions in Switzerland and China, that mean near-surface wind speeds are possibly declining more rapidly at higher elevations than lower elevations in these areas. Using a new dataset of ship-based anemometer wind over the period 1950-2008, positive wind speed trends were found over the Indian Ocean, extending through Indonesia to the northern Pacific while negative trends were found over the Central Pacific (Tokinaga and Xie, 2011). However trends in winds over 1987-2006 differed in sign from satellite derived winds around Australia and parts of southeast Asia.

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 was 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 indicate that storminess in this region exhibits strong inter-decadal variability (Alexandersson et al., 2000; Allan et al., 2009; Wang et al., 2009c). The latter half of the 20th century was punctuated by a peak in storminess around 1990 which according to Wang et al. (2009c) 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). No statistically significant trends have been detected in the global annual number of tropical cyclones to date although a trend has been detected in the intensity of the strongest storms since 1980 (see 3.4.3). Regarding other phenomena associated with extreme winds, studies on thunderstorms, tornadoes and mesoscale convective complexes are too few in number to be used to infer extreme wind speed change.

The AR4 did not address the causes of changes in extreme winds but reported that anthropogenic forcing is *likely* to have contributed to changes in wind patterns, affecting extratropical storm tracks in both hemispheres although it was noted that the observed changes in the Northern Hemisphere circulation are larger than those simulated in response to 20th-century forcing change. The relationship between mean and severe winds and natural modes of variability has been investigated in several post-AR4 studies. On the British Columbian coast, Abeysirigunawardena et al. (2009) found that higher extreme winds tend to occur during the negative (i.e., cold) ENSO phase. The generally increasing trend of mean wind speeds over recent decades in Antarctica is consistent with the change in the nature of the Southern Annular Mode towards its high index state (Turner et al., 2005). Donat et al. (2010b) concluded that 80% of storm days in Central Europe are connected with westerly flows which occur primarily during the positive phase of the NAO. Declining trends in wind over China have mainly been linked to circulation changes due to a weaker land-sea thermal contrast (Xu et al., 2006; Jiang et al., 2010a; Guo et al., 2011). Vautard et al. (2010) attribute the slow down in surface winds over most of the continental northern mid-latitudes to changes in atmospheric circulation (10-50%) and an increase in surface roughness due to biomass increases (25-60%) which are supported by regional climate model simulations. Wang et al. (2009d), formally detected a link between external forcing and positive trends in the high northern latitudes and negative trends in the northern mid-latitudes using a proxy for wind (geostrophic wind energy) in the boreal winter. Trends in the central Mediterranean were found to be positively correlated with temperature but not with the NAO index (Pirazzoli and Tomasin, 2003).

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 (2007a) reported that it was likely that future tropical cyclones (typhoons and hurricanes) would become more intense, with larger peak wind speeds associated with ongoing increases of tropical SSTs. It also reported that there was higher confidence in the projected poleward shift of the storm tracks and associated changes in wind patterns. Since the AR4 there have been several studies which have focussed on future changes to extreme winds. Gastineau and Soden (2009) found agreement between models of a decreased frequency in the tropics and increased frequency in the extratropics of the strongest wind events based on changes in percentiles of 850 hPa wind speed, that are expected to be representative of winds at the surface, using a 17-model ensemble. This is consistent with changes found in 10 m winds by McInnes et al. (2011) in 99th percentile wind speed using daily wind speeds from 19 models from the CMIP3 ensemble. Results from that study, showing changes in mean and 99th percentile winds for 2081-2100 relative to 1981-2000, are shown in Figure 3.9 to illustrate the degree of spatial agreement between the CMIP3 ensemble regarding wind speed change. In

DJF, there is general model agreement on mean wind speed increase over Europe, the northern Pacific, northeastern Canada, north Africa and the Southern Ocean south of 45ºS. Agreement on mean wind speed decrease occurs over the Mediterranean, northeastern to southwestern Indian Ocean and the Southern Hemisphere between 35 and 45ºS. In JJA, model agreement on mean wind speed increase occurs over Europe and the Mediterranean, the tropical Pacific, northern Australia and Indian Ocean between about 10 and 30ºS and the southern Ocean south of 40ºS. Mean wind speed decrease occurs over parts of the Pacific and Indian Oceans from the Equator northwards and in the southern hemisphere at 30-40ºS. Extreme wind speeds (bottom panels of Figure 3.9) show consistency between models over a large portion of the globe in the direction of change, which are in many areas consistent with the direction of change of the mean winds. Increases in extremes occur in the high latitudes of both hemispheres and decreases across the lower latitudes as reported by Gastineau 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 parts of Asia and eastern North America. In JJA, agreement on increases in extremes of up to 5% are seen in eastern South America, northern Australia, the south Pacific between 10 and 20ºS, parts of Africa and much of the Southern Ocean, while agreement on decrease is seen across large parts of the Atlantic and Indian Oceans, the northeast Pacific and northern North America. In some areas such as eastern Asia in DJF, models agree on declining mean winds together with an increase in extreme winds whereas over the south Pacific, southern Australia and Indian Ocean at around 30ºS models agree on an increasing trend in mean winds together with declining trends in extreme winds. While these maps indicate where models produce consistent changes in mean and extreme winds, it should be noted that high agreement across GCMs on a particular sign of extreme wind change may not necessarily indicate a more reliable result because models at their current resolution are unable to resolve small scale phenomena such as tropical cyclones, tornadoes and mesoscale convective complexes that are associated with particularly severe winds and this lowers the confidence in the extreme wind changes particularly in the regions most influenced by these phenomena. For instance, Diffenbaugh et al. (2008) noted that increased atmospheric greenhouse gas concentrations may cause some of the atmospheric conditions conducive to tornadoes such as atmospheric instability to increase due to increasing temperature and humidity, while others such as vertical shear to decrease due to reduced pole-to-equator temperature gradient. They concluded that this limited confidence in the sign of any possible change in tornado activity.

[INSERT FIGURE 3.9 HERE

Figure 3.9: The average of the projected 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., (2011).]

In addition to the global studies, several regional studies of projected winds have also been undertaken and while these provide detail over specific regional areas there is still considerable variation in results related to the different models and methods used. Debernard and Roed (2008) projected statistically significant increases in 99th percentile winds over 2071-2100 relative to 1961-1990 across much of northern Europe, the British Isles and the ocean to the west and decreases to the south of Iceland in several models under various SRES emission scenarios (A2, B2, A1B). Rockel and Woth (2007) projected an increase in winter and a decrease in autumn of 99th percentile daily mean wind speed from eight RCMs over 2071-2100 relative to 1961-1990, over European areas influenced by North Atlantic extra-tropical cyclones. Donat et al. (2010a; 2011) reported an increase of between 19 and 33% of wind storm days in winter over large parts of Central Europe, associated with an increase in intensity of cyclones and a 5% increase in associated winds for the end of the 21st Century relative to the late 20th Century in an ensemble of 9 GCMs although the changes were not statistically significant in all models. Haugen and Iversen (2008) dynamically downscaled four GCMs using an RCM and noted that daily maximum wind speeds in the future climate become more frequent over large parts of northern Europe. Beniston et al. (2007) used 9 RCMs to downscale two GCMs and found that extreme wind speeds increased and become more northwesterly between 45° and 55°N, except over and south of the Alps, for 2071-2100 relative to 1961-1990, although 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. In contrast, Sterl et al. (2009) using a 17 member ensemble of a single GCM found an increase in strong winds from the southwest rather than the north. Leckebusch et al (2008) used storm indices applied to GCM simulations and found that high wind speeds in the future climate increased due to both an increase in the storm wind speed magnitude and the length of the storm tracks. Rauthe et al. (2010) dynamically downscaled ECHAM5 at better than 20 km resolution over the period 2021-2050 relative to 1971-2000 for A1B, A2 and B1 using two RCMs and reported a change in the 10-year wind speed of +6 to -1.5 % over northern Germany and a slight decrease in the majority of simulations over central and southern Germany. Pinto et al. (2007a) used an ensemble of simulations from a GCM forced with A1B and A2 scenarios to estimate changes to insured loss potential (a function of excesses of 98th percentile wind and population density) at the end of the 21st century and found increases everywhere with largest changes in Germany and France, and smallest changes for Portugal and Spain. Over China, Jiang et al. (2010b) projected decreases in winter and annual mean wind speed for 2081-2100 compared to 1971-1990 based on two RCMs that downscale two different GCMs. Sailor et al. (2008) statistically downscaled winds from four GCMs, to develop projections of winds over five airports in the northwest U.S. and the results for 2050 suggested that summertime wind speeds might decrease by 5–10%, while changes to wintertime wind speeds were less certain.

In summary, post-AR4 studies provide considerable new evidence of changes in wind speed across the globe. A declining trend has been detected in mean wind speed across much of the Northern Hemisphere continents. In one study this has been attributed in part to circulation changes and in part to increasing surface roughness. However, due to the various shortcomings associated with anemometer data and the inconsistency in anemometer and reanalysis trends in some regions, we have *low confidence* in the causes of the trends at this stage. We have also *low confidence* in how the observed trends in mean wind speed relate to trends in strong winds. The relatively few studies of projected extreme winds, combined with the different models, regions and methods used to develop projections of this quantity, means that we have *low confidence* in projections of changes in strong winds.

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 not well understood, but a variety of extremes such as floods, drought or even heatwaves may occur more or less frequently than present in the monsoon regions as a consequence of climate change. Generally, 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 the monsoons can be characterized more broadly than via precipitation only, thus monsoon changes might be better depicted by large-scale dynamics, circulation or moisture convergence. However, few studies have focused on observed changes in the large-scale and 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. The focus in this section is also on total and seasonal rainfall, with most discussions of intense rainfall covered in 3.3.2.

Modeling experiments to assess paleo-monsoons suggest that in the past, during the Holocene due to orbital forcing on a millennial timescale, there was a progressive southward shift of the Northern Hemisphere (NH) summer position of the Intertropical Convergence Zone (ITCZ). This was accompanied by a pronounced weakening of the monsoon systems in Africa and Asia and increasing dryness on both continents, while in South America the monsoon was weaker, as suggested both by models and paleo indicators (Wanner et al., 2008).

The delineation of the global monsoon has been mostly performed using rainfall data or outgoing longwave radiation (OLR) fields (Kim et al., 2008). Zhou et al. (2008b; 2008a) and Wang and Ding (2006) report that the combination of monsoon area and rainfall intensity change has led to an overall weakening trend of global land monsoon rainfall accumulation during the last 54 years. Lau and Wu (2007) identified two opposite time evolutions in the occurrence of rainfall events in the tropics, in overall agreement with the Climate Research Unit's 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 were located in deep convective cores of the ITCZ, South Pacific Convergence Zone, Indian Ocean and monsoon regions.

In the Indo-Pacific region, covering the southeast Asian and north Australian monsoon, Caesar et al. (2011) found low 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 were identified, there was generally a trend towards wetter conditions, in common with the global results of Alexander et al. (2006). Liu et al. (2011) reported a decline in recorded precipitation events in China 1960–2000, which was mainly accounted for by a decrease of light precipitation events, with intensities of 0.1–0.3 mm/day. Some of the extreme precipitation appeared to be positively correlated with a La Niña-like SST pattern, but without suggesting the presence of a trend. With regard to wind changes, Guo et al. (2011) analyzed near-surface wind speed change in China and its monsoon regions from 1969 to 2005 and showed a statistically significant weakening in annual and seasonal mean wind.

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. Sen Roy (2009) investigated changes in extreme hourly rainfall in India, and found widespread increases in 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.

In the African monsoon region, Fontaine et al. (2011) investigated recent observed trends using high-resolution gridded precipitation from the CRU (period 1979–2002), OLR and the NCEP reanalyses. Their results revealed a rainfall increase in north Africa since the mid-90s. Over the longer term, however, Zhou et al. (2008b; 2008a) and Wang and Ding (2006) reported an overall weakening trend of global land monsoon rainfall accumulation during the last 54 years, which was mainly caused by the North African monsoon and South Asian monsoon.

For the North American monsoon region, Cavazos et al. (2008) reported increases in the intensity of precipitation in the mountain sites of northwestern Mexico over the 1961-1998 period, apparently related to an increased contribution from heavy precipitation derived from tropical cyclones. Arriaga-Ramirez and Cavazos (2010) found that total and extreme rainfall in the monsoon region of western Mexico and the U.S. southwest presented a statistically significant increase during 1961–1998, mainly in winter. Groisman and Knight (2008) found that consecutive dry days (see Box 3.2 for definition) with periods longer than one month have significantly increased in the U.S. southwest. Increases in heavy precipitation during 1960-2000 in the South American monsoon have been documented by Marengo et al. (2009a; 2009b), and Rusticucci et al. (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, and indicate that the onset exhibits a marked interannual variability linked to variations in SST anomalies in the Eastern Pacific and tropical Atlantic (Gan et al., 2006; da Silva and de Carvalho, 2007; Raia and Cavalcanti, 2008; Nieto-Ferreira and Rickenbach, 2011).

Attributing the causes of changes in monsoons is difficult because 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. 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.

The observed negative trend in global land monsoon rainfall is better reproduced by atmospheric models forced by observed historical sea surface temperature (SST), than by coupled models without explicit forcing by observed ocean temperatures (Kim et al., 2008). This trend is strongly linked to the warming trend over the central eastern Pacific and the western tropical Indian Ocean (Zhou et al., 2008b). For the west African monsoon, Joly and Voldoire (2010) 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 long-term trend in north African summer 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). 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, though 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 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., 2011).

A variety of factors, natural and anthropogenic, have been suggested as possible causes of variations in monsoons. 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). 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 in Amazonia (Voldoire and Royer, 2004; Mabuchi et al., 2005a, b). Grimm et al. (2007) and 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. The impact of aerosols (black carbon and sulfate) on monsoon regions has been discussed by Meehl et al. (2008), Lau et al. (2006) and Silva Dias et al. (2002). These studies suggest that there are still large uncertainties and a strong model dependency in the representation of the relevant land surface processes and the role of aerosol direct forcing, and resulting interactions (e.g., in the case of land use forcing; Pitman et al., 2009).

Regarding projections of change in the monsoons, 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." As global warming is projected to lead to faster warming over land than over the oceans (e.g., IPCC, 2007a; Sutton et al., 2007), the continental-scale land-sea thermal contrast, a major factor affecting monsoon circulations, may become stronger in summer. 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 derived from the analyses of 15 CMIP 3 global models 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, as noted above.

At regional scales, there is little consensus in GCM projections regarding the sign of future change in the monsoons characteristics, such as 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), and in the southern part of the west African monsoon, but with some decreases in the Sahel in northern summer. In the Australian monsoon in southern summer, an analysis by Moise and Colman (2009) from the entire ensemble mean model of CMIP3 simulations suggested no changes in Australian tropical rainfall during the summer and only slightly enhanced inter-annual variability.

A study of 19 CMIP3 models 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., 2007). A more recent study (Ashfaq et al., 2009) from the downscaling of the NCAR CCSM3 global model using the RegCM3 regional model suggests a 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 resulting in a decrease in summer precipitation in key areas of south Asia.

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 rain 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 of Japan provides favourable conditions for intense precipitation in the Baiu season in Japan (Kanada et al., 2010a). 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 CMIP3 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, even though uncertainties in the projection (and even the simulation) of hourly rainfall are still high.

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 emissions scenario (Marengo et al., 2009a; Soares and Marengo, 2009).

There are many deficiencies in model representation of the monsoons and the processes affecting them, and this reduces confidence in their ability to project future changes. 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, see also Section 3.1.4). 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. Shukla (2007) noted that current climate models cannot even adequately predict the mean intensity and the seasonal variations of the Asian summer monsoon. This reduces confidence in the projected changes in extreme precipitation over the monsoon regions. 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), but 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 coupled GCMs 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). 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 aerosol products 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.

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. Since the above mentioned conclusions have been based on very few studies, and there are many issues with model representation of monsoons and the underlying processes, there is *low confidence* in projections of changes in monsoons, even in the sign of the change. However, one common pattern may be an increase in extreme precipitation (see 3.3.2), though not necessarily induced by changes in monsoon characteristics, and not necessarily in all monsoon regions.

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). The term “Southern Oscillation” refers to a tendency for above average surface atmospheric pressures in the Indian Ocean to be associated with below average pressures in the Pacific, and vice versa. This oscillation is associated with variations in sea surface temperatures (SST) in the east equatorial Pacific. The oceanic and atmospheric variations are collectively referred to as ENSO. 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 abnormally 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. In a La Niña episode the climate anomalies are usually the opposite of those in an El Niño. Pacific islands are strongly affected by ENSO variations. 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.

The AR4 noted that orbital variations could affect the ENSO behaviour (Jansen et al., 2007). Cane (2005) found that a relatively simple coupled model suggested that systematic changes in the El Niño could be stimulated by seasonal changes in solar 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. Vecchi and Wittenberg (2010) concluded 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”. Meehl et al. (2009a) demonstrate that solar insolation variations related to the 11-year sunspot cycle can affect ocean temperatures associated with ENSO.

ENSO 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 ENSO 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 indicates that the phenomenon did continue to operate during the LGM (Tudhope et al., 2001). Thus the paleoevidence indicates that ENSO can continue to operate, although altered perhaps in intensity, through quite anomalous climate periods.

The AR4 noted that the nature of ENSO has varied substantially over the period of instrumental data, with strong events from the late 19th century through the first quarter of the 20th century and again after 1950. An apparent 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). Ocean temperatures in the central equatorial Pacific (the so-called NINO3 index) suggest 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 (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) demonstrated that episodes with the warming centred in the central Pacific exhibit different patterns of Australian rainfall variations relative to the east Pacific centred El Niño events.

The possible role of increased greenhouse gases in affecting the behaviour of ENSO over the past 50-100 years is uncertain. 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. 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., Power and Smith, 2007) suggest that changes in the phenomenon are within the range of natural variability (i.e., that no change has yet been detected, let alone attributed).

Global warming is projected to lead to a mean reduction of the zonal winds across the equatorial Pacific (Vecchi and Soden, 2007b). However, this change should not be described as an “El Niño – like” average change even though during an El Niño episode these winds also weaken, because there is only limited correspondence between these changes in mean state of the equatorial Pacific and an El Niño episode. AR4 determined that all models exhibited continued 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). 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 that although ENSO activity increased when CO_2 concentrations were doubled or quadrupled, a considerable decrease in activity occurred when CO_2 was increased by a factor of 16 times, much greater than is possible through the 21st century (Cherchi et al., 2008), suggesting a high variability of possible ENSO changes as a result of CO_2 changes. The remote impacts, on rainfall for instance, of ENSO may change as CO_2 increases, even if the equatorial Pacific aspect of ENSO 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). However, 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.

A caveat regarding all projections of future behaviour of ENSO arises from systematic biases in the depiction of the ENSO behaviour through the 20th century by models (Randall et al., 2007; Guilyardi et al., 2009). 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 ENSO 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 ENSO, 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 ENSO. 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).

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 ENSO 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 ENSO 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”. They also observe that El Niño and La Niña events will 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. Similarly, Collins et al. (2010) conclude that “despite considerable progress in our understanding of the impact of climate change on many of the processes that contribute to El Niño variability, it is not yet possible to say whether ENSO activity will be enhanced or damped, or if the frequency of events will change.”

In summary, models project a wide variety of changes in El Niño – Southern Oscillation variability and the frequency of El Niño episodes as a consequence of increased greenhouse gas concentrations, and so there is *low confidence* in projections of changes in the phenomenon. However, there is *medium confidence* regarding a projected increase (simulated by most GCMs) in the relative frequency of central equatorial Pacific events, which typically exhibit different patterns of climate variations than do the classical East Pacific events.

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 North 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 northwestern 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, and with anomalously dry conditions over southern South America, New Zealand, and Tasmania and 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. Recent work (Ummenhofer et al., 2008; 2009a; 2009b) has implicated the IOD as a cause of droughts in Australia, and heavy rainfall in east Africa (Ummenhofer et al., 2009c). 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 precipitation extremes over North America (Zhang et al., 2010).

Both the NAO and the SAM have exhibited trends towards their positive phase (strengthened mid-latitude 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). 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. Goodkin et al. (2008) conclude that the variability in the NAO is linked with changes in the mean temperature of the Northern Hemisphere. Dong et al. (2010) demonstrated that some of the observed late 20th century decadal-scale changes in NAO behaviour could be reproduced by increasing the CO_2 concentrations in a coupled model, and concluded that greenhouse gas concentrations may have played a role in forcing these changes. The largest observed trends in SAM occur in December-February, and model simulations indicate that these are due mainly to ozone changes. However it has been argued that anthropogenic circulation changes are poorly characterized by trends in the annular modes (Woollings et al., 2008). Further 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. The time scales of variability in modes such as the AMO and PDO are so long that it is difficult to diagnose any change in their behaviour in modern data.

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, the ability of coupled models to simulate the observed SAM impact on climate variability in the Southern Hemisphere is limited (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).

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 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 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. Conway et al. (2007) reported that model projections of future IOD behaviour showed no consistency. Kay and Washington (2008) reported that under some emissions scenarios, changes in a dipole mode in the Indian Ocean could change rainfall extremes in southern Africa.

In summary, issues with the ability of models to simulate current behaviour of these natural modes, the likely influence of competing factors (e.g., ozone, greenhouse gases) on current and future mode behaviour, and inconsistency between the model projections, means that there is *low confidence* in the ability to project changes in the modes.

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 remained roughly steady over the modern period of geostationary satellites (since around the mid-1970s). 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 (e.g., Rappaport, 2000; Webster, 2008). 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, represent important related impacts. Projected sea level rise will further compound tropical cyclone surge impacts. Tropical cyclones that track northward (southward) in the Northern (Southern) hemisphere 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 regions 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 (sometimes categorized according to the Saffir-Simpson scale). The strongest storms (Saffir-Simpson category 4 and 5) are comparatively rare but are generally responsible for the majority of damage (e.g., Landsea, 1993; Pielke et al., 2008). Additionally, there are marked differences in the characteristics of both observed and projected tropical cyclone variability when comparing weaker and stronger tropical cyclones (e.g., Webster et al., 2005; Elsner et al., 2008; Bender et al., 2010), while records of the strongest storms are potentially less reliable than those of their weaker counterparts (Landsea et al., 2006).

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 the metrics briefly mentioned here 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).

Detection of trends in tropical cyclone metrics such as frequency, intensity, and duration remains a significant challenge. Historical tropical cyclone records 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. (2010) 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 cannot 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 (Emanuel, 2007), but it is a current topic of debate whether local SST or the difference between local SST and 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). Since 2005, accumulated cyclone energy, which is an integrated metric analogous to power dissipation, has been declining globally and is presently at a 40-year low point (Maue, 2009). The present period of quiescence, as well as the period of heightened activity leading up to a high point in 2005, do not clearly represent substantial departures from past variability (Maue, 2009).

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 robust and consistent trend in tropical cyclone rainfall has not yet been established due to a general lack of studies. Similarly, increases in the length of the North Atlantic hurricane season have been noted (Kossin, 2008), but the uncertainty in the amplitude of the trends and the lack of additional studies limits the utility of these results for a meaningful assessment.

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 concluded 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 conclude that it is likely that annual numbers of tropical storms, hurricanes and major hurricanes counts have increased 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.

The present assessment regarding observed trends in tropical cyclone activity is essentially unchanged from the AR4 and the WMO report (Knutson et al., 2010), but differs from the CCSP SAP 3.3 report based on subsequent research elucidating the scope of uncertainties in the historical tropical cyclone data: There is *low confidence* that any reported long-term increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities.

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 (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).

Given the evidence that SST in the tropics has increased due to increasing greenhouse gases, and the theoretical expectation that increases in potential intensity will lead to stronger storms, it is essential to fully understand the relationship between SST and potential intensity. Observations demonstrate a strong positive correlation between SST and the potential intensity. This relationship suggests that SST increases will lead to increased potential intensity, which will then ultimately lead to stronger storms (Emanuel, 2000; Wing et al., 2007). However, there is a growing body of research suggesting that local potential intensity is controlled by the difference between local SST and spatially averaged SST in the tropics (Vecchi and Soden, 2007a; Xie et al., 2010; Ramsay and Sobel, 2011). Since increases of SST due to global warming are not expected to lead to continuously increasing SST gradients, this recent research suggests that increasing SST due to global warming, by itself, does not yet have a fully-understood physical link to increasingly strong tropical cyclones.

The present period of heightened tropical cyclone activity in the North Atlantic, concurrent with comparative quiescence in other ocean basins (e.g., Maue, 2009), is apparently related to differences in the rate of SST increases, as global SST has been rising steadily but at a slower rate than the Atlantic (Holland and Webster, 2007). The present period of relatively enhanced warming in the Atlantic has been proposed to be due to internal variability (Zhang and Delworth, 2009), anthropogenic tropospheric aerosols (Mann and Emanuel, 2006), and mineral (dust) aerosols (Evan et al., 2009). None of these proposed mechanisms provide a clear expectation that North Atlantic SST will continue to increase at a greater rate than the tropical-mean SST.

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 (Kossin and Vimont, 2007). Statistical correlations between necessary ambient environmental conditions (e.g., low vertical wind shear and adequate atmospheric instability and moisture) and tropical cyclogenesis frequency have been well documented (DeMaria et al., 2001) but changes in these conditions due specifically to increasing greenhouse gas do not necessarily preserve the same statistical relationships. For example, the observed minimum SST threshold for tropical cyclogenesis is roughly 26°C. This relationship might lead to an expectation that anthropogenic warming of tropical SST and the resulting increase in the areal extent of the region of 26°C SST should lead to increases in tropical cyclone frequency. However, there is a growing body of evidence that the minimum SST threshold for tropical cyclogenesis increases at about the same rate as the SST increase due solely to CO_2 forcing (e.g., Ryan et al., 1992; Dutton et al., 2000; Yoshimura et al., 2006; Bengtsson et al., 2007; Knutson et al., 2008; Johnson and Xie, 2010). That is, when the SST changes due to greenhouse warming are deconvolved from the background natural variability, that part of the SST variability may have no clear effect on tropical cyclogenesis. In this case, the simple observed relationship between tropical cyclogenesis and SST, while robust, does not adequately capture the relevant physical mechanisms of tropical cyclogenesis.

Another challenge to identifying causes behind observed changes in tropical cyclone activity is introduced by uncertainties in the reanalysis data used to identify environmental changes in regions where tropical cyclones develop and evolve (Bister and Emanuel, 2002; Emanuel, 2010). In particular, heterogeneity in upper-tropospheric kinematic and thermodynamic metrics complicate the interpretation of long-term changes in vertical wind shear and potential intensity, both of which are important environmental controls of tropical cyclones.

Based on a variety of model simulations, the expected long-term changes in tropical cyclone characteristics under greenhouse warming is a decrease or little change 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 the SRES A1B warming scenario.

With the exception of the North Atlantic, much of the global tropical cyclone data is 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 both the historical tropical cyclone data and the physical mechanisms underpinning the observed relationships, 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 present assessment regarding detection and attribution of trends in tropical cyclone activity is essentially unchanged from the WMO report (Knutson et al., 2010). The uncertainties in the historical tropical cyclone records, the incomplete understanding of the physical mechanisms linking tropical cyclone metrics to climate change, and the degree of tropical cyclone variability — comprising random processes and linkages to various natural climate modes such as El Niño — provide only low confidence for the attribution of any detectable changes in tropical cyclone activity to anthropogenic influences.

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 CMIP3 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 detection of long-term past increases in tropical cyclone activity is complicated by data quality and signal-over-noise issues (as stated above), theory (Emanuel, 1987) and idealized dynamical models (Knutson and Tuleya, 2004) both 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 in the models for which these metrics were examined. Mean 21st century global cyclone intensity changes under conditions roughly equivalent to A1B emissions scenarios are projected between 2 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 CMIP3 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 an 80% increase in the frequency of Saffir-Simpson category 4 and 5 hurricanes over the next 80 years (A1B scenario). 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.

The projected decreases in global tropical cyclone frequency may be due to increases in vertical wind shear (Vecchi and Soden, 2007c; Zhao et al., 2009; Bender et al., 2010), a weakening of the tropical circulation (Sugi et al., 2002; Bengtsson et al., 2007) associated with a decrease in the upward mass flux accompanying deep convection (Held and Soden, 2006), or an increase in the saturation deficit of the middle troposphere (Emanuel et al., 2008). For individual basins, there is much more uncertainty in projections of tropical cyclone frequency, with changes of up to ±50% or more projected by various models (Knutson et al., 2010). When projected SST changes are considered in the absence of projected radiative forcing changes, Northern Hemisphere tropical cyclone frequency has been found to increase (Wehner et al., 2010), which is congruent with the hypothesis that SST changes alone may not capture the relevant physical mechanisms controlling tropical cyclogenesis (e.g., Emanuel, 2010).

Another type of projection that is sometimes inferred from the literature is based on extrapolation of an observed statistical relationship (see also section 3.2.3). 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 (Vecchi et al., 2008; Knutson et al., 2010). Alternatively, there is a similarly strong relationship between power dissipation and relative SST, which represents the difference between local and tropical-mean 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 (Ramsay and Sobel, 2011).

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 (+2 to +11% globally) is also likely, although increases may not occur in all tropical regions (Knutson et al., 2010). Furthermore, while it is likely that overall global frequency will either decrease or remain essentially unchanged, there is *medium confidence* that the frequency of the most intense storms (e.g., Saffir-Simpson Category 4-5) will increase in some ocean basins. As noted above, 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). This increase is expected to be compounded by increases in intensity as dynamical convergence under the storm is enhanced. Models in which tropical cyclone precipitation rates have been examined 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. Confidence in future projections in particular ocean basins is undermined by the inability of global models to reproduce accurate details at scales relevant to tropical cyclone genesis, track, and intensity evolution. Of particular concern is the limited ability of global models to accurately simulate upper-tropospheric wind (Cordero and Forster, 2006; Bender et al., 2010), which modulates vertical wind shear and tropical cyclone genesis and intensity evolution.

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.

In summary, there is *low confidence* that any reported long-term increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities. The uncertainties in the historical tropical cyclone records, the incomplete understanding of the physical mechanisms linking tropical cyclone metrics to climate change, and the degree of tropical cyclone variability provide only *low confidence* for the attribution of any detectable changes in tropical cyclone activity to anthropogenic influences. There is *low confidence* in projections of changes in tropical cyclone genesis, location, tracks, duration, or areas of impact. 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. It is *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, and an increase in mean tropical cyclone maximum wind speed (+2 to +11% globally) is *likely*, although increases may not occur in all tropical regions. While it is *likely* that overall global frequency will either decrease or remain essentially unchanged, there is *medium confidence* that the frequency of the most intense (e.g., Saffir-Simpson Category 4-5) storms will increase in some ocean basins.

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 are the main poleward transporter of heat and moisture and may be accompanied by adverse weather conditions such as windstorms, the build up of waves and storm surges or extreme precipitation events. 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 atmospheric instabilities such as a disturbance along a zone of strong temperature contrast (baroclinic instabilities), which is a reservoir of available potential energy that can be converted into the kinetic energy associated with extratropical cyclones. Intensification of the cyclones may also take place due to diabatic (temperature changes not related to adiabatic vertical displacement) processes such as release of energy due to phase changes of water (latent heat release) (Gutowski et al., 1992). Why should we expect climate change to influence extratropical cyclones? A simplified line of argument would be that both the low and high level pole to equator temperature gradients may change in a climate change scenario leading to a change in the atmospheric instabilities responsible for cyclone formation and growth (baroclinicity). Changes in precipitation intensities within extratropical cyclones will change the latent heat release. In addition, changes in the extratropical stormtracks are, according to theories on wave–mean flow interaction, associated with changes in the large-scale flow (Robinson, 2000; Lorenz and Hartmann, 2003). A latitudinal shift of the upper tropospheric jet would be accompanied by a latitudinal shift in the extratropical storm track. It is however still unclear to what extent a latitudinal shift of the jet changes the storm track activity rather than shifting it latitudinally (Wettstein and Wallace, 2010). Even within the simplified outline above the possible impact of climate change on the extratropical cyclone development is clearly not trivial.

When validated using reanalyses with similar horizontal resolution, modern climate models are found to represent the general structure of the storm track pattern well (Bengtsson et al., 2006; Greeves et al., 2007; Ulbrich et al., 2008; Catto et al., 2010). However, using data from five different coupled models the rate of transfer of zonal available potential energy to eddy available potential energy in synoptic systems was found to be too large yielding too much energy and an overactive energy cycle (Marques et al., 2011). Models tend to have too zonal stormtracks and some show a poor extension of the stormtracks into Europe (Pinto et al., 2006; Greeves et al., 2007; Orsolini and Sorteberg, 2009). It has also been noted that representation of cyclone activity may depend on the dynamical core and the horizontal resolution of the model (Jung et al., 2006; Greeves et al., 2007).

Paleoclimatic proxies for extratropical cyclone variability are still few, but progress is being made in using coastal dunefield development and sand grain content of peat bogs as proxies for storminess. Papers covering parts of western Europe indicate enhanced sand movement in European coastal areas during the Little Ice Age (Wilson et al., 2004; de Jong et al., 2006; Clemmensen et al., 2007; de Jong et al., 2007; Clarke and Rendell, 2009; Sjogren, 2009). It should be noted that sand influx is also influenced by sediment availability, which is controlled mainly by the degree of vegetation cover and the moisture content of the sediment (Li et al., 2004; Wiggs et al., 2004). Intense cultivation, overgrazing and forest disturbance make soils more prone to erosion, which can lead to increased sand transport even under less windy conditions.

Century-long time-series of estimates of extremes in geostrophic wind deduced from triangles of pressure stations, pressure tendencies from single stations (see section 3.3.3 for details) or oceanic variables such as extremes in non-tide residuals are (if these are located in the vicinity of the main stormtracks) possible proxies for extratropical cyclone activity. Trend detection in extratropical cyclone variables such as number of cyclones, intensity, and activity (parameters integrating cyclone intensity, number and possibly duration) became possible with the development of reanalyses, but remains challenging. Problems with the reanalyses have been especially pronounced in the southern hemisphere (Hodges et al., 2003; Wang et al., 2006a). Even though different reanalyses correspond well in the Northern Hemisphere (Hodges et al., 2003; Hanson et al., 2004) changes in the observing system giving artificial trends in integrated water vapor and kinetic energy (Bengtsson et al., 2004) may have influenced trends in both the number and intensity of cyclones. In addition, studies indicate that the magnitude and even the existence of the changes may depend on the choice of reanalysis (Simmonds et al., 2008) and cyclone tracking algorithm (Raible et al., 2008).

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 cited several papers showing increases in the number or strength of intense extratropical cyclones 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 and eastward 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 was also reported in several studies of Arctic cyclone activity (Zhang et al., 2004c; Sorteberg and Walsh, 2008). Using ship-based trends in mean sea level pressure (MSLP) variance (which is tied to cyclone intensity), Chang (2007) found wintertime Atlantic trends to be consistent with (NCEP) reanalysis trends in the Atlantic, but slightly weaker. There are inconsistencies among studies of extreme cyclones in reanalyses, since some studies show an increase in intensity and number of extreme Atlantic cyclones (Geng and Sugi, 2001; Paciorek et al., 2002) while others show a reduction (Gulev et al., 2001). New studies have 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 may be intermittent (Hanna et al., 2008; Matulla et al., 2008; Allan et al., 2009) due to interdecadal shifts in the location of the positions of the NAO pressure centers (Vicente-Serrano and Lopez-Moreno, 2008; Zhang et al., 2008b). A possible influence of the PNA on the entrance of the North Atlantic stormtrack (over Newfoundland) has been reported by Pinto et al. (2011). It should be noted that there is some suggestion that the reanalyses 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. Long-term European storminess proxies show no clear trends over the last century (see section 3.3.3 for details).

Studies using reanalyses and in situ data for the last 50 years have noted an increase in the number and intensity of north Pacific wintertime intense extratropical cyclone systems since the 1950s (Graham and Diaz, 2001; Simmonds and Keay, 2002; Raible et al., 2008) and cyclone activity (Zhang et al., 2004c), but signs of some of the trends disagreed when different tracking algorithms or reanalysis products are used (Raible et al., 2008). A slight positive trend has been found in north Pacific extreme cyclones (Geng and Sugi, 2001; Gulev et al., 2001; Paciorek et al., 2002). Using ship measurements, Chang (2007) found intensity related wintertime trends in the Pacific to be about 20%–60% of that found in the reanalysis. Long-term in situ observations of north Pacific cyclones based on observed pressure data are considerably fewer than for coastal Europe. However, using hourly tide gauge records at the western coast of the U.S. as a proxy for storminess, an increasing trend in the extreme winter non-tide residuals (NTR) has been observed the last decades (Bromirski et al., 2003; Menendez et al., 2008). 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. 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, in particular over the eastern north Pacific with 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 during El Niño events.

Based on reanalyses North American cyclone numbers have increased over the last 50 years, with no statistically significant change in cyclone intensity (Zhang et al., 2004c). Hourly MSLP data from Canadian stations showed that winter cyclones have become significantly more frequent, longer lasting, and stronger in the lower Canadian Arctic over the last 50 years (1953–2002), but less frequent and weaker in the south, especially along the southeast and southwest Canadian coasts (Wang et al., 2006a). Further south, a tendency toward weaker low-pressure systems over the past few decades was found for U.S. east coast winter cyclones using reanalyses, but no statistically significant trends in the frequency of occurrence of systems (Hirsch et al., 2001).

Studies on extratropical cyclone activity in northern Asia are few. Using reanalyses a decrease in extratropical cyclone activity (Zhang et al., 2004c) and intensity (Zhang et al., 2004c; Wang et al., 2009b) over the last 50 years has been reported for northern Eurasia (60–40°N) with a possible 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) who reported a decrease in the number of severe storms for mainland China based on an analysis of extremes of observed 6-hourly pressure tendencies over the last 50 years.

Alexander and Power (2009) showed 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 previously noted using reanalyses (Fyfe, 2003; Hope et al., 2006). Frederiksen and Frederiksen (2007) linked the reduction in cyclogenesis at 30°S and southward shift to a decrease in the vertical mean meridional temperature gradient. Pezza et al. (2007) confirmed previous studies using reanalysis showing a trend towards fewer and more intense low pressure systems. A study (Lim and Simmonds, 2009) using the ERA-40 reanalysis instead of the NCEP reanalysis used in previous studies, confirmed the trend towards more intense systems, but did not support the decrease in the number of cyclones seen in previous studies, emphasising the weaker consistency among reanalysis products for the Southern Hemisphere extratropical cyclones. Recent studies support the notion of more cyclones around Antarctica when the Southern Annular Mode (SAM) is in its positive phase and a shift of cyclones toward midlatitudes when the SAM is in its negative phase (Pezza and Simmonds, 2008). Additionally, more intense (and fewer) cyclones seem to occur when the Pacific Decadal Oscillation (PDO) is strongly positive and vice versa (Pezza et al., 2007).

In conclusion, it is *likely* that there has been a poleward shift in the main northern and southern stormtracks, during the last 50 years. The degree of agreement is high between several reanalysis products and through a wide selection of cyclone parameters and cyclone identification methods and European and Australian pressure based storminess proxies are consistent with a poleward shift over the last 50 years indicating that the evidence is robust. Advances have been made in documenting the observed decadal and multidecadal variability of extratropical cyclones using proxies for storminess. So the recent poleward shift should be seen in light of new studies with longer time spans that indicate that the last 50 years coincide with relatively low cyclonic activity in northern coastal Europe in the beginning of the period. Several studies using reanalyses suggest an intensification of high latitude cyclones, but there is still insufficient knowledge of how changes in the observational systems are influencing the reanalyses so even when the level of agreement is high among the studies the evidence cannot be considered to be strong. Other regional changes in intensity and the number of cyclones have been reported. The level of agreement between different studies using different tracking algorithms, different reanalysis or different cyclone parameters is still low. Thus, our confidence in the amplitude, and in some regions the sign, of the regional changes is *low*.

Regarding possible causes of the observed poleward shift, 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, but an anthropogenic influence on extratropical cyclones was not formally detected, owing to large internal variability and problems due to changes in observing systems (Hegerl et al., 2007).

Anthropogenic influence on the sea level pressure distribution has been detected in individual seasons (Giannini et al., 2003; Gillett et al., 2005; Wang et al., 2009d). 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., 2009d). However, the models generally simulate smaller changes than observed and also appear to under-estimate the internal variability, reducing the robustness of their detection results. New idealized studies have advanced the physical understanding of how stormtracks may respond to changes in the underlying surface conditions, indicating that a uniform SST increase weakens (reduced cyclone intensity or number of cyclones) and shifts the stormtrack poleward 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), but the average global cyclone activity is not expected to change much under moderate greenhouse gas forcing (O'Gorman and Schneider, 2008; Bengtsson et al., 2009).

In summary, anthropogenic influence on the observed poleward shift in extratropical cyclones activity is *about as likely as not*. It has not formally been detected. However indirect evidence such as anthropogenic influence on the sea level pressure distribution and trend patterns in atmospheric storminess inferred from geostrophic wind and ocean wave heights has been found. In addition, increasing physical understanding that SST changes and greenhouse gas forcing influences extratropical cyclone storm tracks, enhances our confidence in this assessment.

The AR4 reports that in 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).

A northern hemisphere poleward shift in the upper tropospheric stormtrack due to increased anthropogenic forcing is supported by post-AR4 studies (Lorenz and DeWeaver, 2007). It should be noted that other studies indicate that the poleward shift is less clear when models including a full stratosphere and ozone recovery are used (Son et al., 2008) and the strength of the poleward shift is often seen more clearly in upper-level quantities than in low-level transient parameters (Ulbrich et al., 2008). Post-AR4 single model studies support the projection of a reduction in extratropical cyclones averaged over the northern 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 were accompanied by significant increases in total and extreme precipitation.

Models tend to project a reduction of wintertime cyclone activity throughout the mid-latitude North Pacific and for some models a northeastern 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 (Teng et al., 2008; Laine et al., 2009). Over the North Atlantic stormtrack many models project an eastward or southeastward extension of the stormtrack (Ulbrich et al., 2008; Laine et al., 2009) with some models projecting a reduction in cyclone frequency along the Canadian east coast (Bengtsson et al., 2006; Watterson, 2006; Pinto et al., 2007b; Teng et al., 2008; Long et al., 2009). Using bandpassed MSLP from 16 CMIP3 coupled GCMs, Ulbrich et al. (2008) showed regional increases of the storm track activity over the Eastern North Atlantic/Western European area and Donat et al. (2010a) projected an increase in wind storm days for central Europe between 19 and 33% by the end of the 21st century (the increase varies according to the definition of storminess and one model projects a decrease) using 7 different coupled models. New results on Southern Hemisphere cyclones confirm the previously projected poleward shift in stormtracks under increased greenhouse gases (Lim and Simmonds, 2009). That study projected a reduction of Southern Hemisphere extratropical cyclone frequency and intensity in midlatitudes but a slight increase at high latitude.

Detailed analyses of changes in physical mechanisms related to cyclone changes in coupled climate models are still few. O'Gorman (2011) showed that changes in mean available potential energy of the atmosphere can account for much of the varied response in storm-track intensity to global warming implying that changes in storm-track intensity are sensitive to competing effects of changes in temperature gradients and static stability in different atmospheric levels. Using two coupled climate models, Laine et al. (2009) indicate that the primary cause for synoptic activity changes at the western end of the northern hemisphere storm tracks is related to the baroclinic conversion processes linked to mean temperature gradient changes in localized regions of the western oceanic basins. They also found downstream changes in latent heat release during the developing and mature stages of the cyclone to be of importance and indicated that changes in diabatic process may be amplified by the upstream baroclinic changes (stronger (weaker) baroclinic activity in the west gives stronger (weaker) latent heat release downstream). Pinto et al. (2009) found that regional increases in track density and intensity of extreme cyclones close to the British isles using a single model was associated with an eastward shift of the jet stream into Europe, more frequent extreme values of baroclinicity, and stronger upper level divergence. The modelled reduction in Southern Hemisphere extratropical cyclone frequency and intensity in the midlatitudes has been attributed to the tropical upper tropospheric warming enhancing static stability and decreasing baroclinicity while an increased meridional temperature gradient in the high latitudes is suggested to be responsible for the increase of cyclone activity in this region (Lim and Simmonds, 2009). In addition to details in the modelled changes in local baroclinicity and diabatic changes, the geographical pattern of modelled response in cyclone activity has been reported to likely be influenced by the individual model's structure of intrinsic modes of variability (Branstator and Selten, 2009).

In summary it is *likely* that there has been a poleward shift in the main northern and southern stormtracks, during the last 50 years. The degree of agreement is high between different studies and data indicating that the evidence is robust. Anthropogenic influence on this observed poleward shift in extratropical cyclone activity is *about as likely as not*. It has not formally been detected. It is *about as likely as not* that an increased anthropogenic forcing will give a reduction in the number of mid-latitude cyclones averaged over each hemisphere. Confidence in a poleward shift of the upper tropospheric storm tracks due to future anthropogenic forcings is only *medium*. Regional changes may be substantial and IPCC AR4 simulations show some regions with medium degree of agreement. However, studies using different analysis techniques, different physical quantities, different thresholds and different atmospheric vertical levels to represent cyclone activity and storm tracks result in different projections of regional changes. This leads to *low confidence* in region-specific projections.

3.5. Observed and Projected Impacts on the Natural Physical Environment

3.5.1. Droughts

Drought is generally "a period of abnormally dry weather long enough to cause a serious hydrological imbalance" (see IPCC SREX glossary and Box 3.2). While lack of precipitation (i.e., meteorological drought, Box 3.2) is often the primary cause of drought, increased evapotranspiration induced by e.g., enhanced temperature or radiation (e.g., Dai et al., 2004; Easterling et al., 2007; Corti et al., 2009), as well as preconditioning (pre-event soil moisture, lake, snow and/or groundwater storage) can contribute to the emergence of soil moisture and hydrological drought (Box 3.2). 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. Box 3.2 provides a discussion of the issue of drought definition and a description of commonly used drought indices. In order to understand the impact of droughts (e.g., on crop yields, general ecosystem functioning, water resources and electricity production), the timing, the duration, the intensity and the spatial extent need to be characterized. Other weather elements may interact to increase the impact of droughts: enhanced air temperature leads to enhanced evaporative demand, as does enhanced wind speed or increased incoming radiation. 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. In addition, via land-atmosphere interactions, drought also has the potential to impact other weather and climate elements such as temperature and precipitation and associated extremes (Koster et al., 2004b; Seneviratne et al., 2006a ; Hirschi et al., 2011; see also Section 3.1.4).

The AR4 reported that very dry areas (PDSI < -3) had 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 temperatures) have occurred (Breda and Badeau, 2008; Kallis, 2008; Büntgen et al., 2010); hence the current situation is not unprecedented.

START BOX 3.2 HERE

Box 3.2: The Definition of Drought

What is Drought or Dryness?
The IPCC SREX glossary defines drought as follows:
"A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term, therefore any discussion in terms of precipitation deficit must refer to the particular precipitation-related activity that is under discussion. For example, shortage of precipitation during the growing season impinges on crop production or

ecosystem function in general (due to soil moisture drought also termed agricultural drought), and during the runoff and percolation season primarily affects water supplies (hydrological drought). Storage changes in soil moisture and groundwater can also be strongly affected by evapotranspiration excesses in addition to precipitation deficits. A period with an abnormal precipitation deficit is defined as a meteorological drought. A megadrought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more".

As highlighted in the above definition, drought can be defined from different perspectives, depending on the involved stakeholders. The scientific literature commonly distinguishes *meteorological drought*, which refers to deficit of precipitation, *soil moisture drought* (often called *agricultural drought*), which refers to deficit of (mostly root zone) soil moisture, and *hydrological drought*, which refers to negative anomalies in streamflow, lake and/or groundwater levels (e.g., Heim Jr, 2002). We use here the term soil moisture drought instead of agricultural drought, despite the widespread use of the latter (e.g., Heim Jr, 2002; Wang, 2005), because soil moisture deficits have several additional effects beside those on agroecosystems, most importantly on other natural or managed ecosystems (including both forests and pastures), on building infrastructure (Corti et al., 2009), and health through impacts on heatwaves (Section 3.1.4).

Water scarcity which is caused additionally by overuse from human activities does not lie within the scope of this chapter (see Chapter 4); however it should be noted that increasing pressure on water resources by human uses may exert a positive feedback on drought e.g., via declining groundwater levels as a result of an intensive use of superficial and groundwater for agriculture. Drought should not be confounded with aridity, which describes the general characteristic of an arid climate. Indeed, drought is considered a recurring feature of climate occurring in any region and defined with respect to the average climate of the given region (e.g., Dai, 2011). Nonetheless, effects of droughts are not linear, given the existence of e.g., discrete soil moisture thresholds affecting vegetation and surface fluxes (e.g., Koster et al., 2004b; Seneviratne et al., 2010), which means that the same precipitation deficit or radiation excess relative to normal will not affect different regions equally. In this chapter we often use the term "*dryness*" instead of "drought" as a more general qualifier.

Drought Drivers

From a surface perspective (soil moisture or hydrological droughts), the two main drivers for droughts are precipitation deficit and/or evapotranspiration excess (Box 3.2, Figure 1). There are few examples of systems uniquely affected by precipitation deficits. Because soil moisture, groundwater and surface waters are associated with water storage, they have a characteristic memory (e.g., Vinnikov et al., 1996; Eltahir and Yeh, 1999; Koster and Suarez, 2001; Seneviratne et al., 2006b) and thus specific response times to drought forcing (e.g., Begueria et al., 2010). Furthermore, the memory is also a function of the atmospheric forcing and system's feedbacks (Koster and Suarez, 2001; Wang et al., 2009a), and the relevant storage is dependent on soil characteristics and rooting depth of the considered ecosystems. This means that drought has a different persistence depending on the affected system, and that it is also sensitive to pre-conditioning (Box 3.2, Figure 1). Effects of pre-conditioning also explain the possible occurrence of multi-year droughts, whereby soil moisture anomalies can be carried over from one year to the next (e.g., Wang, 2005). However, other features can induce drought persistence, such as persistent circulation anomalies, possibly strengthened by land-atmosphere feedbacks (Schubert et al., 2004). The choice of variable (e.g., precipitation, soil moisture, or streamflow) and time scale can strongly affect the ranking of drought events (Vidal et al., 2010).

[INSERT BOX 3.2, FIGURE 1 HERE
Box 3.2, Figure 1: Processes and drivers relevant for meteorological, soil moisture, and hydrological droughts.]

Drought Indicators

Because of the complex definition of droughts, and the lack of soil moisture observations (Section 3.2.1), several proxies have been developed to characterize (meteorological, soil moisture, and hydrological) drought (see e.g., Heim Jr, 2002; Dai, 2011). These proxies include (land-surface, hydrological or climate) model simulations (providing estimates of e.g., soil moisture or runoff), indices based on measured meteorological or hydrological variables, and paleoclimate proxies such as tree rings, speleothems or historical evidence such as harvest dates. We provide here a brief overview on the wide range of drought indices used in the literature.

Some indices are purely based on precipitation data. A widely used index is the Standard Precipitation Index (SPI) (McKee et al., 1993; Lloyd-Hughes and Saunders, 2002), which consists of fitting and transforming a long-term precipitation record into a normal distribution that has zero mean and unit standard deviation. SPI values of -0.5 to -1 correspond to mild droughts, -1 to -1.5 to moderate droughts, -1.5 to -2 to severe droughts and below -2 to extreme droughts. Similarly, values from 0 to 2 correspond to mildly wet to severely wet conditions, and values above 2 to extremely wet conditions (Lloyd-Hughes and Saunders, 2002). The SPI can be computed over several time scales (e.g., 3, 6 or 12 months) and thus indirectly considers effects of accumulating precipitation deficits, which are critical for soil moisture and hydrological droughts. Another index commonly used in the analysis of climate model simulations is the Consecutive Dry Days (CDD) index, which considers the maximum consecutive number of days without rain (i.e., below a given threshold, typically 1mm/day) within a considered period (i.e., year in general; Frich et al., 2002;

Alexander et al., 2006; Tebaldi et al., 2006). Though the SPI and CDD are both only based on precipitation, they do not necessarily only consider the effects of meteorological drought, since periods without rain are bound to have higher radiation forcing and thus possibly positive evapotranspiration anomalies. This is particularly the case because they focus on indirect precipitation characteristics (normalized precipitation anomalies for the SPI, duration of rainfree period for CDD), which do not relate the drought index to a specific precipitation amount.

Some indices consider both precipitation and evapotranspiration forcing, using simple parameterizations for the evapotranspiration estimates. These include the Palmer Drought Severity Index (PDSI) (Palmer, 1965), which measures the departure of moisture balance from normal conditions using a simple water balance model (e.g., Dai, 2011), as well as other indices such as the Precipitation Potential Evaporation Anomaly (PPEA) used in Burke and Brown (2008) and the Standardised Precipitation-Evapotranspiration Index (SPEI) described in Vicente-Serrano et al. (2010). The PDSI has been widely used for decades (in particular in the United States), also in climate-change analyses (e.g., Burke and Brown, 2008; Dai, 2011). The PDSI was originally calibrated for the central United States, which can impair the comparability of the index across regions, and thus it is often of advantage to renormalize the local PDSI (Dai, 2011). This can also be done using the self-calibrated PDSI (Wells et al., 2004). The model underlying the PDSI is essentially a simple bucket model, which is less advanced than more recent land surface and hydrological models.

For the assessment of soil moisture drought, also simulated soil moisture can be considered. Although the soil moisture simulated by (land-surface, hydrological and climate) models often exhibit strong discrepancies in absolute terms, soil moisture anomalies can be compared with simple scalings and generally match reasonably well (e.g., Koster et al., 2009; Wang et al., 2009a). Climate-change studies considering modeled soil moisture include those by Wang (2005), Sheffield and Wood (2008a), Wang et al. (2009a), and Orlowsky and Seneviratne (2011).

Other drought indices are used to quantify hydrological drought (e.g., Heim Jr, 2002; Vidal et al., 2010; Dai, 2011), but are less commonly used in the context of climate-change studies. Further analyses or indices also consider the area affected by droughts (e.g., Sheffield and Wood, 2008a; Dai, 2011) or additional variables (such as snow or vegetation indices from satellite measurements, e.g., Heim Jr, 2002).

Summary

In summary, drought indices often integrate temperature, precipitation and other variables, but may emphasize different aspects of drought and should be carefully selected with respect to the drought characteristic in mind (e.g., Nicholls and Alexander, 2007). For this reason, assessments of changes in drought characteristics with climate change should consider several indices to allow robust conclusions.

END BOX 3.2 HERE

There are still large uncertainties regarding observed global-scale trends in droughts. Globally, increases in the land area affected by drought was identified in two studies based on the PDSI model (Dai et al., 2004; Burke et al., 2006). This trend in the PDSI proxy was found to be largely affected by changes in temperature, not precipitation. On the other hand, based on soil moisture simulations with an observation-driven land surface model for the time period 1950-2000, Sheffield and Wood (2008a) have inferred trends in drought duration, intensity and severity predominantly decreasing, but with strong regional variation (and including increases in some regions). They concluded that there was an overall wetting trends over the considered time period, but also a switch since the 1970s to a drying trend, globally and in many regions, especially in high northern latitudes. Some regional studies are consistent with the results from Sheffield and Wood (2008a), regarding e.g., less widespread increase (or statistically insignificant changes or decreases) in some regions compared to the study of e.g., Dai et al. (2004) (e.g., in Europe, see below). More recently, Dai (2011) by extending the record did, however, find widespread increases in drought both based on various versions of the PDSI (for 1950-2008) and soil moisture output from a land surface model (for 1948-2004). Hence there are still large uncertainties with respect to global assessments of past changes in droughts. Nonetheless, there is some agreement between studies regarding increasing drought occurrence in some regions, although other regions also indicate opposite trends. Table 3.2 provides regional and continental-scale assessments of observed trends in dryness based on different indices (Box 3.2). The following paragraphs provide more details by continents.

In North America, there is *medium confidence* that there has been an overall slight tendency towards less dryness (wetting trend with more soil moisture and runoff; Table 3.2), although analyses for some subregions also indicate tendencies towards increasing dryness. This assessment is based on several lines of evidence, including simulations with different hydrological models as well as PDSI and CDD estimates (Alexander et al., 2006; Andreadis and Lettenmaier, 2006; van der Schrier et al., 2006a; Kunkel et al., 2008; Sheffield and Wood, 2008a; Wang et al., 2009c; Dai, 2011). The most severe droughts in the 20th century have occurred in the 1930s and 1950s, where the 1930s Dust Bowl was most intense and the 1950s drought most persistent (Andreadis et al., 2005) in the U.S., while in Mexico the 1950s and late 1990s were the driest periods. Recent regional trends towards more severe drought conditions were identified over southern and western Canada, Alaska and Mexico.

In Europe, there is *medium confidence* regarding increases in dryness based on some indices in the southern part of the continent, but large inconsistencies between indices in this region, and inconsistent or statistically insignificant trends in the rest of the continent (Table 3.2). Although Dai et al. (2004) found an increase in dryness for most of the European continent based on the PDSI, Lloyd-Hughes and Saunders (2002) and van der Schrier et al. (2006b) concluded, based on the analysis of SPI and self-calibrating PDSI for the 20th century (for 1901-1999, and 1901-2002, respectively), that no statistically significant changes were observed in extreme and moderate drought conditions in Europe (with the exception of the Mediterranean in van der Schrier et al., 2006b). Sheffield and Wood (2008a) also found contrasting dryness trends in Europe, with increases in the southern and eastern part of the continent, but decreases elsewhere. Beniston (2009b) reported a strong increase in warm-dry conditions over all central-southern (incl. maritime) Europe via a quartile-analysis from mid- to the end of the 20th century. Alexander et al. (2006) found trends towards increasing CDD mostly in the southern and central part of the continent, 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). Stahl et al. (2010) investigated streamflow data across Europe and found negative trends (lower streamflow) in southern and eastern regions, and generally positive trends (higher streamflow) elsewhere (especially in northern latitudes). Low flows have decreased in most regions where the lowest mean monthly flow occurs in summer, but vary for catchments which have flow minima in winter and secondary low flows in summer. The exceptional 2003 summer heat wave on the European continent (see Section 3.3.1) was also associated with a major soil moisture drought, as could be inferred from satellite measurements (Andersen et al., 2005), model simulations (Fischer et al., 2007a; 2007b), and impacts on ecosystems (Ciais et al., 2005; Reichstein et al., 2007).

There is *low to medium confidence* in dryness trends in South America (Table 3.2). For the Amazon, repeated intense 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, (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; 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 Asia there is overall *low confidence* in trends in dryness both at the continental and regional scale, mostly due to spatially varying trends, except in East Asia where a range of studies, based on different indices, show increasing dryness in the second half of the 20th century (Table 3.2). 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 African monsoon regions, related to warming of the tropical oceans, and variability related to the El Niño–Southern Oscillation. There is overall *low* to *medium confidence* regarding regional dryness trends in Africa (Table 3.2).

For Australia Sheffield and Wood (2008a) only found very limited increases in dryness from 1950-2000 based on soil moisture simulated using existing climate forcing (mostly in southeastern Australia) and some marked decreases in dryness in Central Australia and the northwestern part of the continent. Dai (2011), for an extended period until 2008 and using different PDSI variants as well as soil moisture output from a land surface model, found a more extended drying trend in the eastern half of the continent, but also a decrease in dryness in most of the western half. Jung et al. (2010) inferred from a combination of remote sensing and global eddy covariance flux observations that in particular the decade after 1998 became drier in Australia (and parts of Africa and South America), leading to decreased evapotranspiration, but it is not clear if this is a trend or just decadal variation.

In conclusion, following the assessment of the AR4 which was largely based on one study, subsequent work has drawn a more differentiated picture both regionally and temporally. There is not enough evidence at present to suggest high confidence in observed trends in dryness due to lack of direct observations, some geographical inconsistencies in the trends, and some dependencies of inferred trends on the index choice. There is *medium confidence* that since the 1950s some regions of the world have experienced more intense and longer droughts (e.g., southern Europe, West Africa, East Asia) but also opposite trends exist in other regions (e.g., Central North America, Northwestern Australia).

The AR4 (Hegerl et al., 2007) concluded 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 including a detection study which identified an anthropogenic fingerprint in a global PDSI data set with high significance (Burke et al., 2006).

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; 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). 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 2005/2006 U.S. drought in the southeastern U.S. was 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). For soil moisture and streamflow drought 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). This could mean that increasing CO_2 levels alleviate soil moisture and streamflow drought, but this result is still debated. Hence, 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). We thus assess that there is *medium confidence* (see also Section 3.1.5) that anthropogenic influence has contributed to the increase in the droughts observed in the second half of the 20th century.

The AR4 assessed that projections at the time indicated an increase in droughts in particular in subtropical and mid-latitude areas (Christensen et al., 2007). An increase in dry spell length and frequency was 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 was 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 and hydrological models mostly support the projections from AR4, as summarized in the following paragraphs (see also Table 3.3), although we assess the overall confidence in drought projections as *medium* given the definitional issues associated with dryness (Box 3.2) and the partial lack of agreement in model projections when based on different dryness indices (see below). Indeed, 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 CDD to more complex indices of soil moisture and hydrological drought (Box 3.2). 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). These various distinctions are generally not considered and most currently available studies only assess changes in very few (most commonly one or two) dryness indices.

On the global scale, Burke and Brown (2008) provided an analysis of projected changes in drought based on four indices (SPI, PDSI, PPEA and simulated soil moisture anomaly; for definitions see Box 3.2) using two model ensembles: one based on a GCM expressing uncertainty in parameter space, and a multi-model ensemble of 11 GCM simulations from the CMIP3. Their analysis revealed that SPI, based solely on precipitation, showed little change in the proportion of the land surface in drought, and that all the other indices, which include a measure of the atmospheric demand for moisture, showed a statistically significant increase with an additional 5%–45% of the land surface in drought. This study also highlighted large uncertainties in regional changes in drought. This is also consistent with the more recent analysis from Orlowsky and Seneviratne (2011) for projections of changes in two drought indices (CDD and simulated soil moisture) on the annual and seasonal (DJF and JJA) time scales based on a larger ensemble of (23) GCM simulations from the CMIP3 (Figure 3.10; 2080-2100 vs 1980-2000, A2 scenario). It can be seen that the two indices partly agree on some areas of increased drought (e.g., on the annual time scale, in the Mediterranean, Central Europe, Central North America, Southern Mexico, and South Africa). But some regions where the models show consistent increases in CDD (e.g., Australia, Northern Brazil) do not show consistent decreases in soil moisture. Conversely, regions displaying a consistent decrease of CDD (e.g., in Northeastern Asia) do not show a consistent increase in soil moisture. The large uncertainty of drought projections is particularly clear from the soil moisture projections, with e.g., no agreement among the models regarding the sign of changes in DJF in most of the globe. These results regarding changes in CDD and soil moisture are consistent with other published studies (Wang, 2005; Tebaldi et al., 2006; Burke and Brown, 2008; Sheffield and Wood, 2008b; Sillmann and Roeckner, 2008) and the areas that display consistent increasing drought tendencies for both indices have also been reported to display such tendencies for additional indices (e.g., Burke and Brown, 2008; Dai, 2011). Sheffield and Wood (2008b, their Figure 10) examined projections in drought frequency (for droughts of duration of 4-6 month and longer than 12 months, estimated from soil moisture anomalies) based on simulations with 8 GCMs and the SRES scenarios A2, A1B, and B1. They concluded that drought was projected to increase in several regions under these three scenarios (mostly consistent with those displayed in Figure 3.10 for soil moisture changes), although the projections of drought intensification were stronger for the more extreme emissions scenarios (A2 and A1B) than for the more moderate scenario (B1). Regions showing statistically significant increases in drought frequency were found to be broadly similar for all three scenarios, despite the more moderate signal in the B1 scenario (their Figures 8 and 9). This study also highlighted the large uncertainty of scenarios for drought projections, as scenarios were found to span a large range of changes in drought frequency in most regions, from close to no change to two- to three-fold increases (their Figure 10).

Regional climate simulations over Europe also highlight the Mediterranean region as being affected by more severe droughts, consistent with available global projections (Table 3.3; see also Giorgi, 2006; Beniston et al., 2007; Mariotti et al., 2008; Planton et al., 2008). Mediterranean (summer) droughts are projected to start earlier in the year and last longer. Also, increased variability during the dry and warm season is projected (Giorgi, 2006). One GCM-based study projected one to three weeks of additional dry days for the Mediterranean by the end of the century (Giannakopoulos et al., 2009). 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 a consensus of most climate-model projections of 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) project increases in consecutive dry days, although consensus between models is only found in the interior of the continent. African studies indicate the possibility of relatively small scale (500 km) heterogeneity of changes in precipitation and drought, based on climate model simulations (Funk et al., 2008; Shongwe et al., 2009).

Global and regional studies of hydrological drought (Hirabayashi et al., 2008b; Feyen and Dankers, 2009) project a higher likelihood of streamflow drought by the end of this century, with a substantial increase in the number of drought days (defined as streamflow below a specific threshold) during the last 30 years of the 21st century over North and South America, central and southern Africa, the Middle East, southern Asia from Indochina to southern China, and central and western Australia. Some regions, including Eastern Europe to central Eurasia, inland China, and northern North America, project increases in drought. In contrast, wide areas over eastern Russia project a decrease in drought days. At least in Europe, streamflow drought is primarily projected to occur in the frost-free season.

[INSERT FIGURE 3.10 HERE
Figure 3.10: Projected annual and seasonal changes of two dryness indices: Consecutive dry days (CDD, days with pr < 1mm) and average soil moisture (mrso); CMIP3 projections, 2080-2100 time frame minus 1980-2000 time frame (A2 relative to 20C3M simulations), annual (top), DJF (middle) and JJA (bottom). Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].]

Increased confidence in modelling drought stems from consistency between models and satisfactory simulation of drought indices during the past century (Sheffield and Wood, 2008a; Sillmann and Roeckner, 2008). Inter-model agreement is stronger for long-term droughts and larger spatial scales (in some regions, see above discussion), 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 of the 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 sea surface temperatures (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; van den Hurk and van Meijgaard, 2010), and possibly - as only recently highlighted – also feedbacks between droughts, fires and aerosols (Bevan et al., 2009). Furthermore, the development of soil moisture 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 plant 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 understood yet (Hungate et al., 2003; Piao et al., 2007; Bonan, 2008; Teuling et al., 2009). The space-time development of hydrological drought as a response to a meteorological drought and the associated soil moisture drought (drought propagation, e.g., Peters et al., 2003) also needs more attention. There is some understanding of these issues at the catchment scale (e.g., Tallaksen et al., 2009), but these need to be extended to the regional and continental scales. This would lead to better understanding of the spotted maps of hydrological droughts, which would contribute to a better identification and attribution of droughts and help to improve global hydrological models and land surface models.

In summary, there is *medium confidence* that since the 1950s some regions of the world have experienced more intense and longer droughts, in particular in southern Europe, West Africa, and East Asia, but also opposite trends exist in other regions (e.g., Central North America and Northwestern Australia). New studies have improved the understanding of the mechanisms leading to drought. Post-AR4 studies indicate that there is *medium confidence* in a projected increase of duration and intensity of soil moisture and hydrological drought in some regions of the world, in particular in the Mediterranean, Central North America, and Southern Africa. Definitional issues and lack of data preclude higher confidence than *medium i*n observations of drought changes, while these issues plus the inability of models to include all the factors likely to influence droughts preclude stronger confidence than *medium* in the projections.

3.5.2. Floods

A flood is "the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged" (glossary of the American Meteorological Society). Floods include river floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods. 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). 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, soil moisture content and vertical distribution), rate and timing of snow/ice melt, urbanisation, existence of dikes, dams, and reservoirs (Bates et al., 2008). Along coastal areas flooding may be associated with storm surge events (Section 3.5.5). A change in the climate physically changes many of the factors affecting floods (e.g., precipitation, snow cover, soil moisture content, sea level, glacial lake conditions) 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 complex and difficult. This chapter focuses on the spatial, temporal and seasonal changes in high flows and peak discharge in rivers related to climate change. River discharge simulation under a changing climate scenario requires a set of GCM or RCM outputs (e.g., precipitation and surface air temperature) and a hydrological model. A hydrological model may consist of a land surface model of GCM or RCM and a river routing model. Different hydrological models may yield quantitatively different river discharge, but in general they do not yield different signs of the trend if the same GCM/RCM outputs are used. So the ability of models to simulate floods, in particular regarding the signs of the past and future trends, largely depends on the ability of GCM/RCM to simulate precipitation changes. The ability of GCM/RCM to simulate temperature is important for river discharge simulation in snowmelt- and glacier-fed rivers. More details on the ability and uncertainties in hydrological projections are described later in this subsection. 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 (Section 3.5.3) and coastal impacts (Section 3.5.5). Glacial lake outburst floods are discussed in Section 3.5.6. Literature on the impact of climate change on pluvial floods is scarce, but the changes in heavy precipitation discussed in Section 3.3.2 may imply changes in pluvial floods in some 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 more than 100 years (Rodier and Roche, 1984). However, this can be overcome partly by using pre-instrumental flood data from documentary records (archival reports, in Europe continuous over the last 500 yrs) (Brazdil et al., 2005), and from geological indicators of paleofloods (sedimentary and biological records over centuries to millennia scales) (Kochel and Baker, 1982). Analysis of these pre-instrumental flood records have revealed that (1) flood magnitude and frequency are very sensitive to subtle alterations in atmospheric circulation, with greater sensitivity for the largest "rare" floods (50-year flood and higher) than for 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, similar to some 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.

The AR4 concluded that no gauge-based evidence had been found for a climate-related trend in the magnitude/frequency of floods during the last decades (Rosenzweig et al., 2007). However, it also pointed to possible changes that may imply trends in flood occurrence with climate change. For instance, Trenberth et al. (2007) highlighted a catastrophic flood that occurred along several central European rivers in 2002, although no flood nor mean precipitation trends could be identified in this region; however there was a trend to increasing precipitation variability which itself could imply an enhanced probability of flood occurrence. Regarding the spring flow peak, the AR4 concluded with high confidence that abundant evidence was found for an earlier occurrence in snowmelt- and glacier-fed rivers (Rosenzweig et al., 2007; Bates et al., 2008), though we expressly note here that a change in flow peak does not necessarily imply nor preclude changes in flood magnitude or frequency in the affected regions.

Although trends in flood magnitude/frequency might be expected in regions where temperature change affects snowmelt or ice cover (in particular northern high-latitude and polar regions), widespread evidence of such changes is not available. For example, 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, though a significant shift of spring discharge to earlier dates has been found (Shiklomanov et al., 2007). Lindström and Bergström (2004) mentioned that it is difficult to conclude that flood levels are increasing in the analysis of runoff trends in Sweden for 1807-2002.

In the U.S. and Canada during the 20th century and in the early 21st century, there is no compelling evidence for changes in the magnitude/frequency of floods (Lins and Slack, 1999; Douglas et al., 2000; McCabe and Wolock, 2002; Cunderlik and Ouarda, 2009; Villarini et al., 2009). There are relatively abundant studies on the changes and trends for rivers in Europe such as rivers in Germany and its neighbouring regions (Mudelsee et al., 2003; Tu et al., 2005; Yiou et al., 2006; Petrow and Merz, 2009), in the Swiss Alps (Allamano et al., 2009), in France (Renard et al., 2008), in Spain (Benito et al., 2005), and in the UK (Robson et al., 1998; Hannaford and Marsh, 2008), but a continental-scale assessment of the changes in the flood magnitude/frequency for Europe is difficult to provide because geographically organized patterns are not seen in the reported changes.

The number of analyses based on stream gauge records for rivers in other parts of the world is limited. Available (limited) analyses for Asia suggest the following changes: the annual flood maxima of the lower Yangtze region show an upward trend over the last 40 years (Jiang et al., 2008), the likelihood for extreme floods in the Mekong river has increased during the second half of the 20th century (Delgado et al., 2009), and both upward and downward trends are identified 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, 2011). 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. For example, Conway et al. (2009) concluded that robust identification of hydrological change was severely limited by data limitations and other reasons for sub-Saharan Africa. Di Baldassarre et al. (2010) found no evidence that the magnitude of African floods has increased during the 20th century.

The above analysis indicates that research subsequent to the AR4 still does not show clear and widespread evidence of observed changes in the magnitude/frequency of floods at the global level based on instrumental records, and there is thus *low confidence* regarding the magnitude and even the sign of these trends. The main reason for this lack of confidence is due to *lack of literature and evidence*, since instrumental records of floods at gauge stations are limited in space and time, which limits the number of analyses. Pre-instrumental flood data can provide information for longer periods, but these data are even scarcer. There is abundant evidence for an earlier occurrence of spring peak river flows in snowmelt- and glacier-fed rivers (*high confidence*), though this feature may not necessarily be linked with (nor does preclude) changes in extreme floods in the concerned regions. Assessed observed changes in heavy precipitation events (Section 3.3.2) are, however, *likely* to imply past changes in (pluvial) flood occurrence in some regions.

The possible causes for changes in floods were assessed by Bates et al. (2008), a cross-cutting technical paper based on the AR4, but cause-and-effect between external forcing and changes in floods was not explicitly discussed nor in the AR4. More recent literature has, however, detected the influence of anthropogenically-induced climate change in variables that affect floods, such as aspects of the hydrological cycle including mean precipitation (Zhang et al., 2007a), heavy precipitation (see Section 3.3.2), and snowpack (Barnett et al., 2008), though a direct link to trends in floods is still not established. The influence of anthropogenically-induced climate change is nonetheless clearly detected in streamflow regimes in the western USA (Barnett et al., 2008; Hidalgo et al., 2009).

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 from those caused by human regulation of the river systems. River engineering and land use may have altered flood probability. Many dams are designed to reduce flood. Large dams have resulted in large scale land use change and may have changed the effective rainfall in some regions (Hossain 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 falls 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 observed warming over several decades has affected the magnitude of the snowmelt flow peak, but projected warming may result either in an increase in spring flood peak (where winter snow depth increases, (Meehl et al., 2007b) or a decrease in spring flood peak (i.e., presumably because of decreased snow cover and amounts; (Hirabayashi et al., 2008b; Dankers and Feyen, 2009).

There is still a lack of studies identifying an influence of observed warming over several decades on rain-generated peak streamflow trends because of uncertainty in the observed streamflow data and low signal to noise ratio. However, limited evidence has emerged that anthropogenic warming may have influenced the likelihood of rainfall-dominated floods in some river basins in Europe (Pall et al., 2011). Overall, there is *low confidence* (*limited evidence*) that anthropogenic warming has affected the magnitude/frequency of floods, though it has detectably influenced several components of the hydrological cycle such as precipitation and snow melt, which may impact flood trends. The assessment of causes behind the changes in floods is inherently complex and difficult. Nevertheless, there is *high confidence* in that observed warming over several decades, that is attributable to anthropogenic forcing, has *likely* been linked to earlier spring flow peaks in snowmelt- and glacier-fed rivers (Rosenzweig et al., 2007; Bates et al., 2008), though this may not necessarily imply higher flood occurrence.

The number of studies that investigated projected flood changes in rivers especially at a regional or a continental scale was limited when the AR4 was published. A rare example introduced in the AR4 was the study by Milly et al.(2002) which based on monthly river discharge calculated from climate model outputs identified projected changes (mostly increases) in ‘large’ floods at selected extratropical river basins larger than 20,000 km^2. Projections of flood changes at the catchment/river-basin scale were also not abundantly cited in the AR4. Nevertheless, Bates et al. (2008) argued that projected increases in the frequency of heavy precipitation events (see also 3.3.2) would also imply an enhanced risk of rain-generated floods in the affected regions.

The number of regional- or continental-scale studies of projected changes in floods 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 indicated 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. Most notable changes are projected to occur in northern and northeastern Europe in the late 21st century, but the results vary between studies. 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. 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.

Projections of flood changes at the 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 such as Asia (Asokan and Dutta, 2008; Dairaku et al., 2008), the Middle East (Fujihara et al., 2008), South America (Nakaegawa and Vergara, 2010), and Africa are rare. Most projections for rain-dominated catchments were carried out, and are being carried out, because climate models project rainfall intensification in regions where these catchments are located, which is anticipated to be a cause of more frequent or more severe floods. 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).

It has been recently recognized that the choice of GCMs is the largest source of uncertainties in hydrological projections if the same emission scenario is adopted, 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, whether downscaling, bias-correction, and the choice of hydrological models are of secondary importance 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 northern and northeastern 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).

The number of projections of flood magnitude/frequency changes is still limited at regional and continental scales. Projections at the catchment/river-basin scale are also not abundant in the peer-reviewed scientific literature, especially for regions outside Europe and North America. In addition, considerable uncertainty remains in the projections of flood changes, especially regarding their magnitude and frequency. Therefore, our assessment is that there is *low confidence* (due to *limited evidence* as well as *to low agreement of projections)* in future projections of changes in flood magnitude and frequency derived from river discharge simulations. Nevertheless, an increase in the magnitude and/or frequency of rain-generated floods is anticipated in some catchments and regions where short-term (e.g., daily) rainfall extremes and/or long-term (e.g., monthly, wet-season total) rainfall extremes are projected to increase. This assessment is an extension of Bates et al. (2008) because we consider here several spatio-temporal scales in rain-generated floods. However we note that heavy precipitation as well as mean precipitation are projected to either decrease and/or increase depending on the regions considered (Section 3.3.2), and that changes in several variables (e.g., precipitation totals, frequency and intensity, snow cover and snow melt, soil moisture) are relevant for changes in floods. Confidence in change of one of these components alone may thus not be sufficient to confidently assess future changes in flood occurrence. The earlier shifts of spring peak flows in snowmelt- and glacier-fed rivers are robustly projected (Kundzewicz et al., 2007; Bates et al., 2008); thereby, the earlier shifts can be assessed as *very likely*, though this may not necessarily be relevant for flood occurrence. There is *low confidence* (*limited evidence and low agreement*) in the projected magnitude of the earlier peak flows in snowmelt- and glacier-fed rivers.

In summary, there is *low confidence* at the global level regarding observed changes in the magnitude and frequency of floods, and even the sign of such changes. There is *low confidence* in future projections of changes in flood magnitude and frequency. Nevertheless, an increase in the magnitude and/or frequency of rain-generated floods is anticipated in some catchments and regions where short-term (e.g., daily) rainfall extremes and/or long-term (e.g., monthly, wet-season total) rainfall extremes are projected to increase. Earlier spring peak flows in snowmelt and glacier-fed rivers are *very likely*, but there is low confidence in their projected magnitude.

3.5.3. Extreme Sea Levels

Extreme sea levels are caused by severe storms such as tropical or extratropical cyclones. The associated drop in atmospheric pressure and strong winds can produce storm surges at the coast, which may be further elevated by wave setup caused by an onshore flux of momentum due to wave breaking. Extreme sea levels can be expected to change in the future as a result of both mean sea level rise and changes in atmospheric storminess, neither of which will be spatially uniform across the globe. As discussed in sections 3.4.4 and 3.4.5, changes in the frequency or intensity of tropical and extratropical cyclones, and their location, may be expected, and these changes may differ between ocean basins. Variations in the rate of sea level rise will occur as a result of variations in heat content in the ocean which lead to different rates of thermal expansion (e.g., Bindoff et al., 2007; Church et al., 2010; Timmermann et al., 2010). In addition, rapid melting of ice sheets will lead to non-uniform rates of sea level rise across the globe due to adjustments in the Earth's gravitational field (e.g., Mitrovica et al., 2010).

Mean sea level has varied considerably over glacial time scales as the extent of ice caps and glaciers have fluctuated with global temperatures. Sea levels rose around 130 m since the last glacial maximum 20-25ka before present to around 7000 years ago and reached a level close to present at least 6000 years ago (Lambeck et al., 2010). As well as the influence on sea level extremes caused by rapidly changing coastal bathymetries (Clarke and Rendell, 2009) and large scale circulation patterns (Wanner et al., 2008), there is some evidence that changes in the behaviour of severe tropical cyclones has changed on centennial time scales which points to non-stationarity in extreme sea level events (Nott et al., 2009). Woodworth et al. (2011) use tide gauge records dating back to the 18th century, and saltmarsh data, to show that sea level rise has accelerated over this time frame.

The AR4 reported there was *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 0.17 [0.12 to 0.22] mm yr^{-1} over the 20th century, 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 AR4 also 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). Since the AR4, Menendez and Woodworth (2010), using data from 258 tide gauges across the globe, has confirmed the earlier conclusions of Woodworth and Blackman (2004) that there was a trend in extreme sea levels globally, more pronounced since the 1970's, and this trend was consistent with trends in mean sea level (see also Lowe et al., 2010). A number of additional studies at particular locations support this finding (e.g., Marcos et al., 2009; Haigh et al., 2010).

Various studies also highlight the additional influence of climate variability on extreme sea level trends. Menendez and Woodworth (2010) report that the El Niño – Southern Oscillation (ENSO) has a large influence on interannual variations in extreme sea levels in the Pacific Ocean and the monsoon regions based on sea level records since the 1970s. In southern Europe, Marcos et al. (2009) report that changes in extremes are also significantly negatively correlated with the North Atlantic Oscillation (NAO). Ullmann et al. (2007) concluded that maximum annual sea levels in the Camargue had risen twice as fast as mean sea level during the 20th century due to an increase in southerly winds associated with a general rise in sea level pressure over central Europe (Ullmann et al., 2008). Sea level trends from two tide gauges on the north coast of British Columbia from 1939-2003 were twice that of mean sea level rise, the additional contribution being due to the strong positive phase of the Pacific Decadal Oscillation (PDO) which has lasted since the mid-1970s (Abeysirigunawardena and Walker, 2008). 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, also noting that positive sea level anomalies of 10 to 20 cm that often persisted for several months during El Niño events produced an increase in storm surge peaks over this time. The spatial extent of these oscillations and their influence on extreme sea levels across the Pacific have been discussed by Merrifield et al. (2007). Church et al. (2006b) examined changes in extreme sea levels before and after 1950 in two tide gauge records of approximately 100 years on the east and west coasts of Australia respectively. At both locations a stronger positive trend was found in the sea level 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) noted an increase in the number and duration of positive storm surges in the decade 1996 to 2005 compared to previous decades which may be due to a combination of mean sea level rise and changes in wind climatology resulting from a southward shift in the South Atlantic high.

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) and may be influenced by modes of climate variability such as the PDO on the Canadian west coast (e.g., Abeysirigunawardena and Walker, 2008; Marcos et al., 2009; Menendez and Woodworth, 2010). These studies are consistent with 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.

The AR4 (Meehl et al., 2007b) projected sea level rise for 2090–2099 relative to 1980–1999. The rise from ocean thermal expansion, glaciers and ice caps, and modelled ice sheet contributions is projected to be 18–59 cm which incorporates a 90% confidence range, across all scenarios. 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 by 2090-2099 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.

Several studies since the AR4 have developed statistical models that relate 20th century (e.g., Rahmstorf, 2007; Horton et al., 2008) or longer (e.g., Grinsted et al., 2009; Vermeer and Rahmstorf, 2009) temperature and sea level rise to extrapolate future global mean sea level. These alternative approaches yield projections of sea level rise by 2100 of 0.50-1.20 m (Rahmstorf, 2007), 0.47 - 1.00 m (Horton et al., 2008), 0.9 to 1.3 m for the A1B Scenario (Grinsted et al., 2009) and 0.75 – 1.90 m (Vermeer and Rahmstorf, 2009). However, as noted by Cazenave and Llovel (2010) future rates of sea level rise may be less closely associated with global mean temperature if ice sheet dynamics play a larger role in the future. Using glacier models, Pfeffer et al. (2008) found that sea level rise of more than 2 m by 2100 is physically implausible. An estimate of 0.8 m by 2100 that included increased ice dynamics was considered most plausible.

New studies, whose focus is on quantifying the effect of storminess changes on storm surge, have been carried out over the northern European region since the AR4 and mostly find an increase along the North Sea coastline. This is consistent with increased storminess and wind speed as indicated by most models across this region in Figure 3.9. Debernard and Roed (2008) investigated storm surge changes over Europe in four regionally downscaled GCMs including two run with B2, one with A2 and one with an A1B emission scenario. Despite large inter-model differences, statistically significant changes between 2071-2100 and 1961-1990 consisted of decreases in the 99th percentile surge heights south of Iceland, and an 8-10% increase along the coastlines of the eastern North Sea and the northwest British Isles, which occurred mainly in the winter season. Wang et al. (2008) projected a significant increase in wintertime storm surges around Ireland except the south Irish coast over 2031-2060 relative to 1961-1990 using a downscaled GCM under an A1B scenario. Sterl et al. (2009) concatenated the output from a 17 member ensemble of A1B simulations from a GCM over the model periods 1950-2000 and 2050-2100 into a single longer time series to estimate 10000 year return values of surge heights along the Dutch coastline. No statistically significant change in this value was projected for the 21st century because projected wind speed changes were not associated with the surge-generating northerlies but rather non-surge generating southwesterlies.

Other studies have undertaken a sensitivity approach to compare the relative impact on extreme sea levels of severe weather changes and mean sea level rise. 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, would produce an increase in sea levels that were 20 to 35% of the upper end of the A1FI sea level rise projection for 2070. Brown et al. (2010) also investigated the relative impact of sea level rise and wind speed change on an extreme storm surge in the eastern Irish Sea. Both studies concluded that sea level rise rather than meteorological changes 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 is 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 whereby cyclone characteristics and tracks are represented by statistical models, from which populations of synthetic cyclones representing current climate can be constructed. Such models can also be perturbed to represent projected future climates (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 (the combined sea level due to the storm surge and tide), again with mean sea level rise producing the larger contribution to changes in future sea level extremes. However, one study that has incorporated scenarios of sea level rise in the hydrodynamic modelling of hurricane-induced sea level extremes on the Louisiana coast found that increased coastal water depths had a large impact on surge propagation, increasing storm surge heights by 2 to 3 times the sea level rise scenario, particularly in wetland-fronted areas (Smith et al., 2010).

To summarise, post-AR4 studies provide additional evidence that trends in extreme sea level across the globe reflect the trends in mean sea level, suggesting that mean sea level rise rather than changes in storminess are largely contributing to this increase (although data are sparse in many regions and this lowers the confidence in this assessment). It is considered *likely* that sea level rise has led to a change in extreme water levels. Studies into changes in future extreme sea levels have poor global coverage being mainly focussed on Europe although these studies generally provide further evidence for an increase in extreme sea levels due to changes in storminess in the North Sea. Other studies that have compared the relative contribution to future extreme sea levels of mean sea level and storminess changes find that, despite large uncertainties in the magnitude of these contributions in the future, sea level rise has been found to lead to larger increases in total water level, although the studies are limited in number and geographical coverage. On the basis of these studies of observed trends in extreme sea levels it is *very likely* that sea level rise will contribute to increases in extreme sea levels in the future. While changes in storminess may contribute to changes in sea level extremes, the limited geographical coverage of studies to date and the uncertainties associated with storminess changes overall (Sections 3.4.4 and 3.4.5) means that a general assessment of the effects of storminess changes on storm surge is not possible at this time.

3.5.4. Waves

Severe waves threaten the safety of coastal inhabitants and those involved in maritime activities and can damage and destroy coastal and marine infrastructure. 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. Wave properties that influence these processes include wave height, the wave energy directional spectrum, 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 - the height from trough to crest of the highest one third of waves) and metrics of extreme waves, such as high percentiles or wave heights above particular thresholds. One study examines trends in SWH, mean wave direction and peak wave period (Dodet et al., 2010).

Wave climates have changed over paleo-climatic time scales. Wave modelling using paleobathymetries over the past 12000 years indicates an increase in peak annual SWH of around 40% due to the increase in relative sea level, which redefines the location of the coastline and hence progressively extends the fetch length in most of the shelf sea regions (Neill et al., 2009). Major circulation changes that result in changes in storminess and wind climate (see section 3.3.3) have also affected wave climates. Evidence of enhanced storminess determined from sand drift and dune building along the western European coast indicates that enhanced storminess occurred over the period of the little ice age (1570-1900) and the mid Holocene (~8200 BP; Clarke and Rendell, 2009).

The AR4 reported statistically significant positive trends in SWH over the period 1950 to 2002 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 and declining trends around Australia, and parts of the Philippine, Coral and Tasman Seas (Trenberth et al., 2007), based on 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 positive trends in SWH and extreme waves in the north Atlantic and north Pacific. Wang et al. (2009c) found that SWH 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. They also found that storminess around the 1880s was of similar magnitude to that in the 1990s, consistent with Gulev (2004). In a regional North Sea hindcast, Weisse and Günther (2007) found a positive trend in 99th percentile wave height from 1958 to the early 1990s followed by a declining trend to 2002 over the southern North Sea, except on the UK North Sea coast where negative trends occurred over much of the hindcast period. A wave hindcast over the north-eastern Atlantic Ocean over the period 1953-2009 revealed a significant positive trend in SWH and a counterclockwise shift in mean direction in the north and a slight but not significant increase in peak wave period in the northeast. In the south, no trend was found for SWH or wave period while a clockwise trend in mean direction was found (Dodet et al., 2010). On the North American Atlantic coast, Komar and Allan (2008) found a statistically significant trend of 0.059 m/yr in waves exceeding 3 m during the summer months over 30 years since the mid-1970s at Charleston, South Carolina, with lower but statistically significant trends at wave buoys further north. These trends were associated with an increase in intensity and frequency of hurricanes over this period. In contrast, wintertime waves, generated by extratropical storms, were not found to have experienced a statistically significant change. Along the U.S. west coast, SWH is strongly correlated with El Niño. However positive trends were also found in SWH and extreme wave height from the mid-1970s to 2006 in wave buoy data (Allan and Komar, 2006), in hindcast SWH over 1948-1998 (Adams et al., 2008) and for excesses of the 98th percentile SWH over 1985-2007 (Menendez et al., 2008). Positive though not statistically significant trends in annual mean SWH were found over south-eastern South America for in situ wave data over the 1996-2006 period and in satellite wave data over 1993-2001 while simulated wave fields using reanalysis wind forcing over the period 1971-2005 produced statistically significant trends in SWH (Dragani et al., 2010). Trends at particular locations may be also influenced by local factors. For example, Suursaar and Kullas (2009) reported a slight decreasing trend in mean SWHs from 1966–2006 in the Gulf of Riga within the Baltic Sea, while the frequency and intensity of high wave events (i.e., the difference between the maximum and 99th percentile wave height) showed rising trends. These changes were associated with a decrease in local average wind speed, but an intensification of westerly winds and storm events occurring further to the west.

In the Southern Ocean SWH derived from satellite observations was found to be strongly positively correlated with SAM particularly from March to August (Hemer et al., 2010). However, the analysis of reliable long term trends in the Southern Hemisphere remains challenging due to limited in situ data and problems of temporal homogeneity in reanalysis products. For example, Hemer et al. (2010) also found that trends in SWH derived from satellite data over 1998–2000 relative to 1993–1996 were positive only over the Southern Ocean south of 45°S whereas trends were positive across most of the Southern Hemisphere in the corrected ERA-40 reanalysis (C-ERA-40). Furthermore, the frequency of wave events exceeding the 98th percentile over the period 1985-2002 using data from a wave buoy situated on the west coast of Tasmania showed no statistically significant trend whereas a strong positive trend was found in equivalent fields of C-ERA-40 data (Hemer, 2010).

New studies have demonstrated strong links between wave climate and natural modes of climate variability. For example, along the U.S. west coast and the western North Pacific, SWH was found to be strongly correlated with El Niño (Allan and Komar, 2006; Sasaki and Toshiyuki, 2007) and in the southern ocean, SWH was positivity correlated with the SAM. On the U.S. East coast, positive trends in summertime SWH were linked to increasing numbers of hurricanes. In the northeast Atlantic trends in SWH exhibited significant positive (negative) correlations with NAO in the north (south) and more generally, trends in SWH, mean wave direction and peak wave period over the period 1953-2009 were related to the increase in NAO index over this time (Dodet et al., 2010). One study (Wang et al., 2009d) reported 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 SWH in the boreal winter in the high-latitudes of the Northern Hemisphere (especially the northeast North Atlantic), and a decrease in more southerly northern latitudes over the past half century.

The AR4 projected an increase in extreme wave height for many regions of the mid-latitude oceans due to a projected northward movement in storm tracks and associated increases in wind speeds in these regions due to projected increased greenhouse gas concentrations in the atmosphere (Meehl et al., 2007b). At the regional scale, increases in wave height were projected for most mid-latitude areas analysed, including the North Atlantic, North Pacific and Southern Ocean (Christensen et al., 2007) but with low confidence due to the low confidence in projected changes in mid-latitude storm tracks and intensities. Several studies since then have developed wave climate projections, which provide greater evidence for future wave climate change. Global scale projections of SWH were developed by Mori et al. (2010), using a 1.25° resolution wave model forced with projected winds from a 20 km global GCM, in which ensemble-averaged SST changes from the CMIP3 models provided the climate forcing. The spatial pattern of projected SWH change between 2075-2100 and 1979-2004 reflect the changes in the forcing winds, which are generally similar to the mean wind speed changes shown in Figure 3.9. Extreme waves (measured by the average of the top 10 values) were projected to exhibit large increases in the northern Pacific, particularly close to Japan due to an increase in strong tropical cyclones and also the Indian Ocean despite decreases in SWH.

A number of regional studies have also been completed since the AR4 in which forcing conditions were obtained for a few selected emission scenarios (typically B2 and A2, representing low-high ranges) from GCMs or RCMs. These studies provide additional evidence for positive trends in SWH and extreme waves along the western European coast (e.g., Debernard and Roed, 2008; Grabemann and Weisse, 2008), the UK coast (Leake et al., 2007), declines in extreme wave height in the Mediterranean (Lionello et al., 2008) and the southeast coast of Australia (Hemer et al., 2010) and little change along the Portuguese coast (Andrade et al., 2007). However, considerable variation in projections can arise from the different climate models and scenarios used to force wave models, which lowers the confidence in the projections. For example along the European North Sea coast, 99th percentile wave height over the late 21st century relative to the late 20th century is projected to increase by 6-8% by Debernard and Roed (2008) based on wave model simulations with forcing from several GCMs under A2, B2 and A1B greenhouse gas scenarios, whereas they are projected to increase by up to 18% by Grabemann and Weisse (2008) who downscaled two GCMs under A2 and B2 emission scenarios. In one region, opposite trends in extreme waves were projected. Grabemann and Weisse (2008) project negative trends in 99th percentile wave height along the UK North Sea coast, whereas Leake et al. (2007) 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. Hemer et al. (2010) concluded that uncertainties arising from the method by which climate model winds were applied to wave model simulations (e.g., by applying bias-correction to winds or perturbing current climate winds with changes in winds derived from climate models) made a larger contribution to the spread of climate model projections than the forcing from different GCMs or emission scenarios.

In summary, although post-AR4 studies are few and their regional coverage is limited, their findings generally support the evidence from earlier studies of wave climate trends. Most studies find a link between variations in waves (both SWH and extremes) and internal climate variability. Only one study has detected a link between external forcing (anthropogenic and natural) and positive trends in SWH in northern high latitudes and negative trends in northern mid-latitudes. As a result, there is *low confidence* that there has been an anthropogenic influence on extreme wave heights. 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, but the small number of studies, the lack of consistency of the wind projections between GCMs combined with limitations in their ability to simulate extreme winds means there is *low confidence* in the findings. However the strong linkages between wave height and winds and storminess means that it is *likely* that future changes in SWH will reflect future changes in these parameters.

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 both of which would be affected by climate change through rising sea levels and changes in extreme events. Coastal inundation occurs during periods of extreme sea levels due to storm surges and high waves, particularly when combined with high tides. Although tropical and extra-tropical cyclones are the most common causes of sea level extremes, other weather events that cause persistent winds such as anticyclones and fronts can also influence coastal sea levels (e.g., Green et al., 2009; McInnes et al., 2009b). In many parts of the world sea levels are influenced by modes of variability such as the El Niño – Southern Oscillation (ENSO, Section 3.4.2). In the western equatorial Pacific, sea levels can fluctuate up to half a metre between ENSO phases (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 (Lowe et al., 2010). Shoreline position can change from the combined effects of various factors such as:

1. Rising mean sea levels, which causes landward recession of coastlines made up of erodible materials.
2. Subsidence of coastal terrain due to isostatic rebound (Blewitt et al., 2010; Mitrovica et al., 2010), or sediment compaction from the removal of oil, gas and water (Syvitski et al., 2009).
3. Changes in the frequency or severity of transient storm erosion events (Zhang et al., 2004a).
4. Changes in sediment supply to the coast (Stive et al., 2003; Nicholls et al., 2007; Tamura et al., 2010).
5. Changes in wave period due to sea level rise, which alters wave refraction, or in wave direction, which can cause cause realignment of shorelines (Ranasinghe et al., 2004; Bryan et al., 2008; Tamura et al., 2010).
6. The loss of natural protective structures such as coral reefs (e.g., Sheppard et al., 2005; Gravelle and Mimura, 2008) or the reduction of permafrost or sea ice in mid and high latitudes, which exposes soft shores to the effects of waves and severe storms (see 3.5.7, Manson and Solomon, 2007).

The susceptibility of coastal regions to erosion and inundation is related to various physical (e.g., shoreline slope), and geomorphologicical and ecosystem attributes, and therefore may be inferred to some extent from broad coastal characterisations. These include the presence of beaches, rocky shorelines or cliffed coasts; deltas; backbarrier environments such as estuaries and lagoons; the presence of mangroves, saltmarshes or sea grasses, shorelines flanked by coral reefs (e.g., Nicholls et al., 2007) or by permafrost or seasonal sea ice each of which are characterised by different vulnerability to climate change driven hazards. For example, deltas are low-lying and hence generally prone to inundation, while 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 lead to reduced protection 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. Dynamical processes such as vertical land movement also contributes to inundation potential (Haigh et al., 2009). Some coastal regions may be rising due to post-glacial rebound or slumping due to aquifer drawdown (Syvitski et al., 2009). Multiple contributions to coastal flooding such as heavy rainfall and flooding in coastal catchments that coincide with elevated sea levels may also be important. Ecosystems such as coral reefs also play an important role in providing material on which atolls are formed. Large scale oceanic changes that are particularly relevant to both coral reefs and small island countries are discussed in Box 3.3.

The rise in mean sea level by about 120 m since the end of the last ice age (Jansen et al., 2007) has had a profound effect on coastline position around the world. Contributing to the evolution of the coastlines have been changes in action of the ocean on the coast through changes in wave climate (Neill et al., 2009), tides (Gehrels et al., 1995) and changes in storminess (e.g., Clarke and Rendell, 2009).

The AR4 (Nicholls et al., 2007) reported that coasts are experiencing the adverse consequences of impacts such as increased coastal inundation, erosion and ecosystem losses. However, attributing these changes to sea level rise is difficult due to the multiple drivers of change over the 20th century (Nicholls, 2010) and the scarcity and fragmentary nature of data sets which contributes to the problem of identifying and attributing changes (e.g., Defeo et al., 2009). Since the AR4 there have been several new studies that examine coastline changes. 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 with most beaches found to be eroding and faster rates of erosion generally found on islands that had been impacted by a higher number of hurricanes. However, the relative importance of anthropogenic factors, climate variability and climate change on the eroding trends could not be separated quantitatively (Cambers, 2009). In Australia, Church et al. (2008) report that despite the positive trend in sea levels during the 20th century, beaches have generally been free of chronic coastal erosion, but where it has been observed, it has not been possible to unambiguously attribute it 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 Nations (Tuvalu, Kiribati and Federated States of Micronesia) over a 19 to 61 year period using photography and satellite imagery found 43% of islands remained stable and 43% increased in area over the timeframe of analysis, with largest decadal rates of increase in island area ranging from 0.1 to 5.6 hectares. Only 14% of islands studied exhibited a net reduction in area (Webb and Kench, 2010). Despite the small net changes in area, a larger redistribution of land area, consisting of a net lagoonward migration of islands, was evident in 65% of cases. Chust et al. (2009) evaluated the relative contribution of local anthropogenic (non-climate change related) and sea level rise impacts on the coastal morphology and habitats in the 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.

START BOX 3.3 HERE

Box 3.3: Small Islands

Small islands represent a distinct category of locations owing to their small size and highly maritime climates, which means that their concerns and information needs in relation to future climate change differ in many ways from those of the larger continental regions that are addressed in this chapter. Particular challenges exist for the assessment of past changes of climate given the sparse regional and temporal coverage of terrestrial-based observation networks and the limited in situ ocean observing network although observations have improved somewhat in recent decades with the advent of satellite-based observations of meteorological and oceanic variables. However, the short length of these records hampers the investigation of long term trends in the region. The resolution of GCMs is insufficient to resolve small islands and few studies have been undertaken to provide projections for small islands using RCMs (Campbell et al., 2011). In regions such as the Pacific Ocean, large scale climate features such as the South Pacific Convergence Zone and the El Niño – Southern Oscillation (ENSO, Section 3.4.2) have significant influence on the pattern and timing of precipitation, yet these features and processes are often poorly represented in GCMs. The purpose of this box is to present available information on observed trends and climate change projections that are not covered in the other sections of this chapter as well as discuss key aspects of the climate system that are particularly relevant for small islands.

Although the underlying data sources are limited, some data for the Indian Ocean, South Pacific (Fiji) and Caribbean were available in the studies of Alexander et al. (2006) and Caesar et al. (2011). Problems of data availability and homogeneity for the Caribbean are discussed by Stephenson et al. (2008b). Based on standard extremes indices, positive trends in warm days and warm nights and negative trends in cool days and cool nights have occurred across the Indian Ocean and South Pacific region for the period 1971-2005 (Caesar et al., 2011) and the Caribbean for the period 1951-2003 (based on data from Alexander et al., 2006). Based on the same data sources, trends in average total wet day precipitation were positive and statistically significant over the Indian Ocean region, negative over the South Pacific region and weakly negative over the Caribbean. Similarly, trends in heavy and very heavy precipitation were positive over the Indian Ocean, negative over the South Pacific region and close to zero over the Caribbean.

Recent projections of temperature for the Pacific have been undertaken using models from the CMIP3 ensembles (Perkins et al., 2011) that have been assessed in terms of their ability to capture important climate features of the region such as the South Pacific Convergence Zone (Brown et al., 2011) and indicate that, under an A2 emission scenario, most of the South Pacific region will warm by 3°C by 2081-2100 relative to 1981-2000, precipitation will increase by 60% over the Equator, and wind speed will decrease along the Equator and increase further south and tend to a more easterly flow. For the Caribbean, temperatures are projected to increase across the region by 1-4˚C over 2071-2100 relative to 1961-1990 under A2 and B2 scenarios and rainfall is mainly projected to decrease by 25-50% except in the north (Campbell et al., 2011).

Given the low elevation of many small islands, sea level extremes are of particular relevance. In the Pacific, sea level extremes are strongly influenced by tidal extremes (Chowdhury et al., 2007; Merrifield et al., 2007) and depending on whether the tide behaviour is mostly semi-diurnal (two high and low tides per day) or diurnal (one high and low tide per day), there will be a clustering of high spring tides around the time of the equinoxes or the solstices. In addition, ENSO has a strong influence such that sea levels and their extremes are positively (negatively) correlated with the Southern Oscillation Index in the tropical Pacific west (east) of 180° (Church et al., 2006a; Menendez et al., 2010). Tides and ENSO have contributed to the more frequent occurrence of sea level extremes and associated flooding experienced at some Pacific Islands such as Tuvalu in recent years and make the task of determining the relative roles of these natural effects and mean sea level rise difficult (Lowe et al., 2010). Furthermore, the steep shelf margins that surround many islands and atolls in the Pacific support larger wave-induced contributions to sea level anomalies. This suggests that waves are also likely to be a major contributor to positive sea level anomalies for small islands, which has been found to be the case at Midway Atoll in the northern tropical Pacific (Hoeke et al., 2011). Unfortunately, wave observations (including wave direction) are sparse, including those that are co-located with tide gauges, which would facilitate more comprehensive studies of tide, surge and wave extremes in the region (Lowe et al., 2010).

Anthropogenic-induced oceanic changes may reduce the resilience of coral atolls to extreme events such as high waves and storm surge and this may exacerbate extreme impacts. Coral atolls are mainly composed of unlithified or poorly consolidated carbonate sand and gravel, which is supplied by the surrounding reefs. Storms and swell are in many instances the agents of delivery of carbonate material to the shores of atolls (Woodroffe, 2008; Webb and Kench, 2010) and so the health of coral reefs is therefore important for the long term provision of carbonate material for the atolls as sea levels rise in the future. Oceanic changes that could reduce the health of the surrounding reefs and therefore potentially increase severe weather induced erosion and inundation are: (1) warming of the surface ocean, (2) ocean acidification induced by increases in atmospheric carbon dioxide being absorbed into the oceans, and (3) reduction in oxygen concentration in the ocean due to a temperature-driven change in gas solubility. 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). 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. Quantifying these changes and understanding their impact on coral reef health will be important to understanding the impact of anthropogenic climate change.

In summary, the reported increases in warm days and nights and decreases in cool days and nights are of medium confidence over the Caribbean and of low confidence over the Pacific and Indian oceans. There is high confidence in the projected temperature increases across the Pacific and Caribbean. There is insufficient evidence at this time to assess observed trends and future projections in rainfall. The unique situation of small islands in their maritime environments leads to an additional emphasis on oceanic information to understand the risks of climate change. Knowledge and data that is particularly relevant is limited at this stage, and if not

addressed, will hamper efforts to quantify the risks and formulate sound adaptation responses to future climate change for the inhabitants of small islands.

END BOX 3.3 HERE

The AR4, stated with *very high confidence* that the impact of climate change on coasts is exacerbated by increasing human-induced pressures. Consistent with that assessment, the small number of studies that have been completed since the AR4 have been either unable to attribute coastline changes to specific causes in a quantitative way or else find strong evidence for non-climatic causes that are natural and/or anthropogenic.

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, adaptation to climate change required understanding of processes operating on decadal to century time scales, yet this understanding was least developed.

Because of the diverse and complex nature of coastal impacts, assessments of the future impacts of climate change have focussed on a wide range of questions and employed a diverse range of methods, making direct comparison of studies difficult (Nicholls, 2010). Two types of studies are reviewed briefly here; the first are assessments, typically undertaken at the country or regional scale and which combine information on physical changes with the socio-economic implications (e.g., Nicholls and de la Vega-Leinert, 2008); the second type are studies oriented around improved scientific understanding of the impacts of climate change. In terms of coastal assessments, Aunan and Romstad (2008) reported 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) reported that large parts of the coasts in Great Britain (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) reported 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) reported that for Germany 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), characterised future vulnerability in terms of coastal geomorphology, sediment type and tide and wave characteristics, from which it concluded that the tropical northern coastline would be most sensitive to changes in tropical cyclone behaviour while health of the coral reefs may also influence the tropical eastern coastline. The mid-latitude southern and eastern coastlines were expected to be most sensitive to changes in mean sea level, wave climate and changes in storminess. A comparative study of the impact of sea level rise on coastal inundation across 84 developing countries showed that the greatest vulnerability to a 1 m sea level rise was in East Asia and the Pacific in terms of land area, population, GDP, agricultural, urban and wetland areas, whereas sub-Saharan Africa was least affected (Dasgupta et al., 2009).

New models have been developed for the assessment of coastal vulnerability at the global to national level (Hinkel and Klein, 2009). At the local to regional scale, new techniques and approaches have also been developed to better quantify impacts from inundation due to future sea level rise. Bernier et al. (2007) evaluated species vulnerability to inundation from future sea level rise using seasonal return periods of high water and showed that increased inundation of wetlands from spring time storm surges under sea level rise scenarios could adversely affect bird breeding cycles. McInnes et al. (2009a) developed spatial maps of stormtide and using a simple inundation model with high resolution LiDAR data and a land subdivisions data base, identified the impact of inundation on several coastal towns along the southeastern Australian coastline under future sea level and wind speed scenarios. Probabilistic approaches have also been used to evaluate extreme sea level exceedance under uncertain future sea level rise scenarios. Purvis et al. (2008), assumed a plausible probability distribution to the range of future sea level rise estimates and used Monte-Carlo sampling to apply the sea level change to a two-dimensional coastal inundation model. They showed that by evaluating the possible flood related losses (in monetary terms) in this framework they were able to represent spatially the higher losses associated with the low frequency but high impact events instead of considering only a single midrange scenario. Hunter (2010) presented 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. 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), although such methods have not as yet been applied in a climate change context, (Callaghan et al., 2008). Along the Portuguese coast, Andrade et al. (2007) found that projected future climate in the HadCM3 model would 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 U.K. East Anglia coast, the effect of sea level rise, surge and wave climate change on the inshore wave climate was evaluated and the frequency and height of extreme waves were found to increase in the north of the domain (Chini et al., 2010). On the basis of modelling various climate change scenarios over the next 25 years, Coelho et al. (2009) concluded that the effects of sea level rise are less important than changes in wave action along a stretch of the Portuguese coast. Modelling of the evolution of soft rock shores with rising sea levels has revealed a relatively simple relationship between sea level rise and the equilibrium cliff profile (Walkden and Dickson, 2008).

To summarise, recent observational studies that identify trends and impacts at the coast are low in regional coverage and furthermore the quantity and quality of data and methods to attribute changes to particular causes is also low, which means there is *low confidence* that anthropogenic climate change has been a major cause of the observed changes. However, recent coastal assessments at the national and regional scale and process-based studies have provided further evidence of the vulnerability of low-lying coastlines to rising sea levels and erosion, so that in the absence of adaptation there is *high confidence* that locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future.

3.5.6. Glacier, geomorphological and geological impacts

Mountains are prone to mass movements including landslides, avalanches, debris flows and flash floods that can lead to disasters. Changes in mountain glaciers affect these processes, as well as water supply and hydropower generation. Many of the world’s high mountain ranges are situated at the margins of tectonic plates, increasing the possibility of potentially hazardous interactions between climatic and geological processes. The principal drivers are glacier ice mass loss, permafrost degradation, and possible increases in the intensity of precipitation (Liggins et al., 2010; McGuire, 2010). The projected consequences are changes in mass movement on shorter contemporary timescales, and seismicity and volcanic activity on longer, century to millennium timescales. The climate variability that influences these geomorphological phenomenon are simulated by climate models but these phenomena are typically of a regional or local nature. GCMs do not simulate local and regional climate variables with sufficient detail and accuracy to provide high confidence in projections of changes in geomorphological phenomena.

The AR4 assessed past changes in glaciers and concluded that the widespread retreat of glaciers in the world is consistent with warming. However, the impacts of glacier retreat on the natural physical system in the context of changes in extreme events were not assessed in detail. Additionally, the AR4 did not assess geomorphological and geological impacts that might result from anthropogenic climate change.

The most studied change in the high-mountain environment has been the retreat of glaciers (Paul et al., 2004; Kaser et al., 2006; Larsen et al., 2007; Rosenzweig et al., 2007). Alpine glaciers around the world achieved their maximum extent at the end of the Little Ice Age (~1850), and have retreated since then (Oerlemans, 2005), with an accelerated decay during the past several decades (Zemp et al., 2007). Glaciers have retreated in many parts of the world (Francou et al., 2000; Cullen et al., 2006; Thompson et al., 2006; Larsen et al., 2007; Schiefer et al., 2007; Paul and Haeberli, 2008). Rates of retreat that exceed historical experience and internal (natural) variability have become apparent since the beginning of the 21st century (Reichert et al., 2002; Haeberli and Hohmann, 2008).

Outburst floods from lakes dammed by glaciers or unstable moraines (or “Glacial lake outburst floods”, GLOFs) are commonly a result of glacier retreat and formation of lakes behind unstable natural dams (Clarke, 1982; Clague and Evans, 2000; Huggel et al., 2004; Dussaillant et al.2010). In the past century GLOFs have caused 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; Vincent et al., 2010). However, because GLOFs are relatively rare, it is unclear whether their occurrence is changing on either the regional or global scale. Clague and Evans (2000) argue that outburst floods from moraine-dammed lakes may have peaked due to a reduction in the number of the lakes since the end of the Little Ice Age. In contrast, a small, but not statistically significant increase of GLOF events was observed in the Himalayas over the period 1940-2000 (Richardson and Reynolds, 2000) though there has been no GLOF since the 1998 event of Tam Pokhari (Osti and Egashira, 2009) in the region.

Evidence of degradation of mountain permafrost and attendant slope instability has emerged from recent studies in the European Alps (Gruber and Haeberli, 2007; Huggel, 2009) and other mountain regions (Niu et al., 2005; Geertsema et al., 2006; Allen et al., 2011). This evidence includes several recent rock falls, rock slides, and rock avalanches in areas where permafrost thaw is occurring. Landslides with volumes ranging up to a few million cubic metres occurred in the Mont Blanc region (Barla et al., 2000), in Italy (Sosio et al., 2008; Huggel, 2009; Fischer et al., 2011a), in Switzerland and in British Columbia (Evans and Clague, 1998; Geertsema et al., 2006). Very large rock and ice avalanches with volumes of 30 to over 100 million m^3 include the 2002 Kolka avalanche in the Caucasus (Haeberli et al., 2004; Kotlyakov et al., 2004; Huggel et al., 2005), the 2005 Mt. Steller rock avalanche in the Alaska Range (Huggel et al., 2008), the 2007 Mt. Steele ice and rock avalanche in the St. Elias Mountains, Yukon (Lipovsky et al., 2008), and the 2010 Mt. Meager rock avalanche and debris flow in the Coast Mountains of British Columbia.

Quantification of possible trends in the frequency of landslides and ice avalanches in mountains is difficult due to incomplete documentation of past events, especially those that happened before satellite observations became available. Nevertheless, there has been an apparent increase in large rock slides during the past two decades, and especially during the first years of the 21st century in the European Alps, the Southern Alps of New Zealand (Allen et al., 2011; Fischer et al., 2011b) and in northern British Columbia (Geertsema et al., 2006) in tandem with temperature increases, glacier shrinkage, and permafrost degradation.

Research, however, has not yet provided any clear indication of a change in the frequency of debris flows due to recent deglaciation. Debris flow activity at a local site in the Swiss Alps was higher during the 19th century than today (Stoffel et al., 2005). In the French Alps no significant change in debris flow frequency has been observed since the 1950s in terrain above elevations of 2200 m (Jomelli et al., 2004). Processes not, or not directly, driven by climate, such as sediment yield can also be important for changes in the magnitude or frequency alpine debris flows (Lugon and Stoffel, 2010).

Debris flows from both glaciated and unglaciated volcanoes, termed lahars, can be particularly large and hazardous. Lahars produced by volcanic eruptions on the glacier-clad Nevado del Huila volcano in Colombia in 2007 and 2008 were the largest, rapid mass flows on Earth in recent years. Similarly, large mass flows occur on ice-covered active volcanoes in Iceland (Björnsson, 2003), including Eyjafjallajökull in 2010. Large rock and ice avalanches, with volumes up to 30 million m^3, have happened frequently (averaged about one every 4 years) on the glaciated Alaskan volcano, Iliamna, are thought to be related to elevated volcanic heat flow and possibly meteorological conditions (Huggel et al., 2007). In 1998, intense rainfall mobilised pyroclastic material on the flanks of Vesuvius and Campi Flegrei volcanoes, feeding *ca.* 150 debris flows that damaged nearby communities and resulted in 160 fatalities (Bondi and Salvatori, 2003). In the same year, intense precipitation associated with Hurricane Mitch triggered a small flank collapse at Casita volcano in Nicaragua. This slope failure transformed into debris flows that destroyed two towns and claimed 2,500 lives (Scott et al., 2005). Glacier retreat in the area of Bering Glacier in southeast Alaska appears to be modulating the recent seismic record (Sauber et al., 2000; Doser et al., 2007; Sauber and Ruppert, 2008) and may have been a contributing factor for the 1972 St. Elias earthquake (Sauber and Molnia, 2004).

A variety of climate and weather events can have geomorphological and geological impacts. Warming and degradation of permafrost affect slope stability. For example, the 2003 European summer heat wave (Section 3.3.1) caused rapid thaw and thickening of the active layer and trigging a large number of mainly small rock falls (Gruber et al., 2004; Gruber and Haeberli, 2007). Permafrost thaw may increase both the frequency and magnitude of debris flows (Zimmermann et al., 1997; Rist and Phillips, 2005). The frost table at the base of the active layer is a barrier to groundwater infiltration and can cause the overlying non-frozen sediment to become saturated. Snow cover can also affect debris flow activity by supplying additional water to the soil, increasing pore water pressure and initiating slope failure (Kim et al., 2004). Many of the large debris flows in the Alps in the past 20 years were triggered by intense rainfall in summer or fall when the snowline was elevated (Rickenmann and Zimmermann, 1993; Chiarle et al., 2007). Warming may increase the flow speed of frozen bodies of sediment (Kääb et al., 2007; Delaloye et al., 2008; Roer et al., 2008). Rock slopes can fail after they have been steepened by glacial erosion or unloaded (debuttressed) following glacier retreat (Augustinus, 1995). Although it may take centuries or even longer for a slope to fail following glacier retreat, recent landslides demonstrate that some slopes can respond to glacier downwasting within a few decades or shorter (Oppikofer et al., 2008). Twentieth-century warming may have penetrated some decametres into thawing steep rock slopes inn high mountains (Haeberli et al., 1997). Case studies indicate that both small and large slope failures can be triggered by exceptionally warm periods of weeks to months (Gruber et al., 2004; Huggel, 2009; Fischer et al., 2011a).

The spatial and temporal patterns of precipitation, the intensity and duration of rainfall, and antecedent rainfall are important factors in triggering shallow landslides (Iverson, 2000; Wieczorek et al., 2005; Sidle and Ochiai, 2006). In some regions antecedent rainfall is probably a more important factor than rainfall intensity (Kim et al., 1991; Glade, 1998), whereas in other regions rainfall duration and intensity are the critical factors (Jakob and Weatherly, 2003). Landslides in temperate and tropical mountains that have no seasonal snow cover are not temperature-sensitive and may be more strongly influenced by human activities such as poor land-use practises, deforestation, and overgrazing (Sidle and Ochiai, 2006).

Rock and ice avalanches on glaciated volcanoes can be triggered by heat generated by volcanic activity. Their incidence may increase with rising air and rock temperatures (Gruber and Haeberli, 2007) or during or following brief, anomalously warm events (Huggel et al., 2010). Landslides are also favoured by glacier flows, which may destabilize or oversteepen slopes (Tuffen, 2010); by melting ice, which may create weak zones at ice-bedrock interfaces (Huggel, 2009), and by shallow hydrothermal alteration driven by snow and ice melt (Huggel, 2009). On unglaciated high volcanoes in the Caribbean, Central America, Europe, Indonesia, the Philippines and Japan, an increase in total rainfall or an increase in the frequency or magnitude of severe rainstorms could cause more frequent debris flows by mobilizing unconsolidated, volcanic regolith and by raising pore-water pressures, which could lead to deep-seated slope failure. Heavy rainfall events could also influence the behaviour of active volcanoes. For example, Mastin (1994) attributes the violent venting of volcanic gases at Mount St Helens between 1989 and 1991 to slope instability or accelerated growth of cooling fractures within the lava dome following rainstorms, and Matthews et al. (2002) link episodes of intense tropical rainfall with collapses of the Soufriere Hills lava dome on Montserrat in the Caribbean. A large reduction in glacier cover may be responsible for an increase in seismicity in southeast Alaska where earthquake faults are at the threshold of failure (Sauber and Molnia, 2004; Doser et al., 2007). An increase in the frequency of small earthquakes in the Icy Bay area, also in southeast Alaska, is interpreted to be a crustal response to a glacier wastage between 2002 and 2006 (Sauber and Ruppert, 2008). Large-scale ice-mass loss in glaciated volcanic terrain reduces the load on the crust and uppermost mantle, facilitating of the rise of more magma into the crust (Jull and McKenzie, 1996) and allowing magma to reach the surface more easily (Sigmundsson et al., 2010). At the end of the last glaciation, this mechanism resulted in a more than 10-fold increase in the frequency of volcanic eruptions in Iceland (Sinton et al., 2005). Widespread uplift of up to 20 mm y^{-1} is currently occurring in response to thinning of Vatnajökull Ice Cap in Iceland and is expected to cause a future increase in volcanic activity (Sigmundsson et al., 2010).

Phenomena such as ice avalanches, GLOFs, and some landslides that are related to glacier retreat are temperature-sensitive and thus are *likely* to have been affected by anthropogenic warming. There is *low confidence* in an anthropogenic influence on precipitation-driven phenomena such as shallow landslides because an anthropogenic influence on regional precipitation has yet to be established with confidence. Poor land-use practices also may contribute to landslides, and such factors complicate the attribution of changes in geomorphogical and geological impacts to a single factor (e.g., Sidle and Ochiai, 2006).

The AR4 projected that glaciers in mountains will lose additional mass over this century because more ice will be lost due to summer melting than is replenished by winter precipitation (Meehl et al., 2007b). The total area of glaciers in the European Alps may decrease by 20% to more than 50% by 2050 (Zemp et al., 2006; Huss et al., 2008). Atmospheric warming favours rapid glacier mass loss and related mass movements (Huggel et al., 2011). The projected glacier retreat in the 21st century will *likely* form new, potentially unstable lakes. Probable sites of new lakes have been identified for some alpine glaciers (Frey et al., 2010). Rock slope and moraine failures may trigger damaging surge waves and outburst floods from these lakes. The temperature rise also will result in gradual permafrost degradation (Haeberli and Burn, 2002; Harris et al., 2009). Warm permafrost (mean annual rock temperature ~- 2 to 0°C), which is more susceptible to slope failures than cold permafrost, may rise in elevation a few hundred metres during the next 100 years (Noetzli and Gruber, 2009). The response of bedrock temperatures to surface warming through thermal conduction will be slow, but warming will eventually penetrate to considerable depths in steep rock slopes (Noetzli et al., 2007). Other heat transport processes such as advection, however, may induce warming of bedrock at much faster rates (Gruber and Haeberli, 2007). The response of firn and ice temperatures to an increase in air temperature increase is 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; Hoelzle et al., 2010). At higher temperatures, more ice melts and the strength of the remaining ice is lower; as a result, the frequency and perhaps size of ice avalanches may increase (Huggel et al., 2004; Caplan-Auerbach and Huggel, 2007). Warm extremes can trigger large rock and ice avalanches (Huggel et al., 2010), and warm extremes have been projected to increase by several fold by 2050 (Huggel et al., 2010).

Current low levels of seismicity in Antarctica and Greenland may be a consequence of ice-sheet loading. Isostatic rebound associated with accelerated deglaciation of these regions may result in an increase in earthquake activity, perhaps on a timescales as short as 10 – 100 years (Turpeinen et al., 2008; Hampel et al., 2010). Future ice-mass loss on glaciated volcanoes, notably in Iceland, Alaska, Kamchatka, the Cascade Range in the northwest USA, and the Andes, could lead to eruptions, either as a consequence of reduced load pressures on magma chambers or through increased magma–water interaction. Reduced ice load arising from future thinning of Iceland's Vatnajökull Ice Cap is projected to result in an additional 1.4 km^3 of magma produced in the underlying mantle every century (Pagli and Sigmundsson, 2008). Ice-unloading will also promote failure of shallow magma reservoirs; the most likely consequence being a small perturbation of the natural eruptive cycle (Sigmundsson et al., 2010). Ice thinning of 100 m or more on volcanoes with glaciers more than 150 m thick, such as Sollipulli in Chile, may cause more explosive eruptions, with increased tephra hazards (Tuffen, 2010). Additionally, the potential for edifice lateral collapse could be enhanced due to loss of support previously provided by ice (Tuffen, 2010) or to elevated pore-water pressures arising from meltwater (Capra, 2006; Deeming et al., 2010). The likelihood of both volcanic and non-volcanic landslides may also be increased due to greater availability of water, which could destabilize slopes. Many volcanoes provide a ready source of unconsolidated debris that can be rapidly transformed into potentially hazardous lahars by extreme precipitation events. Volcanoes in coastal, near-coastal or island locations in the tropics are particularly susceptible to torrential rainfall associated with tropical cyclones, and such events are projected to increase through this century (see section 3.4.5). The impact of future, large, explosive, volcanic eruptions may also be exacerbated by an increase in extreme precipitation events, by providing an effective means of transferring large volumes of unconsolidated ash and pyroclastic flow debris from the flanks of volcanoes into downstream areas. Following the 1991 Pinatubo eruption in the Philippines, heavy rains associated with tropical storms moved large volumes of volcanic sediment. The sediment dammed rivers, causing massive flooding across the region that continued for several years after the eruption ended (Newhall and Punongbayan, 1996).

In summary, many weather and climate events can have geomorphological and geological impacts. Many other factors, however, also influence these impacts, thus it is difficult to attribute any recent trends in impacts to climate change. As well, the availability of representative long time series of such impacts are rare, so it is difficult to quantitatively identify long-term trends. Nevertheless, there is *medium confidence* that high-mountain debris flows will begin earlier in the year because of earlier snow melt. There is *low confidence* in projected changes in the magnitude and frequency of shallow landslides in temperate and tropical regions, as they depend mainly on frequency and intensities of rainfall events and anthropogenic land-use. It is *likely* that continued permafrost degradation and glacier retreat will further decrease the stability of rock slopes, although there is *low confidence* regarding future locations and timing of large rock avalanches, as these depend on local geological conditions and other non-climatic factors.

3.5.7. High-Latitude Changes including Permafrost

Permafrost is widespread in Arctic, Subarctic, in ice-free areas of Antarctica, and in high-mountain regions, and permafrost regions occupy approximately 23 million km^2 of land areas in the Northern Hemisphere (Zhang et al., 1999). 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 (near surface layer that thaws and freezes seasonally over permafrost) 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).

Limited observations show 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 since the mid-1980s. The magnitude of permafrost temperature increase is up to 1.0°C 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 since the 1980s (Cheng and Wu, 2007). Generally speaking, the magnitude of permafrost temperature increase in continuous permafrost regions is greater than in discontinuous permafrost regions (Osterkamp, 2007). Increases in snow depth 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. Observations show that active layer thickness has increased about 20 cm in the Russian Arctic between the early 1960s to 2000 (Zhang et al., 2005), up to 1.0 m over the Qinghai-Tibetan Plateau since the early 1980s (Wu and Zhang, 2010), with no significant trend in North American Arctic since the early 1990s (Brown et al., 2000). Extensive thermokarst development has been found in Alaska (Yoshikawa and Hinzman, 2003; Osterkamp et al., 2009), in 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). Coasts with ice-bearing permafrost that are exposed to the Arctic Ocean are very sensitive to permafrost degradation. Some Arctic coasts are retreating at a rapid rate of 2 to 3 m yr^{-1} and the rate of erosion along Alaska's northeastern coastline has doubled over the past 50 years (Karl et al., 2009).

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). Trends towards earlier snowfall in autumn and thicker snow cover during winter have resulted in stronger snow insulation effect, and as a result a much warmer permafrost temperature than air temperature in the Arctic. The lengthening of the thaw season and increases in summer air temperature have resulted in changes in active layer thickness. A model simulation suggests there will only be about 10% of current near-surface permafrost remaining by 2100 (Lawrence and Slater, 2005). 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 lakes 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.

In summary, it is *likely* that there has been an increased thawing of permafrost in recent decades, and it is *likely* that it has had physical impacts. It is *very likely* that permafrost temperatures will continue to increase, and it is *likely* that there will be widespread increases in active layer thickness and large reduction in the area of permafrost in the Arctic and Subarctic. 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.

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 and Dulac, 1998; Kellogg and Griffin, 2006). For example, dust from the Saharan region and from Asia may reach North America (McKendry et al., 2007). Most of the GCMs have implemented the processes to simulate sand and dust storms (Textor et al., 2006). Climate variables that are most important to dust emission and transportation such as soil moisture, precipitation and wind are still subject to large uncertainties in the simulations. As a result, the sand and dust storm simulations have large uncertainties as well.

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 the 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 into the present (Prospero and Lamb, 2003; Prospero et al., 2009).

Surface soil dust concentration during a sand and dust storm is controlled by a number of factors. 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 in source regions 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 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 have played 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 (Gong et al., 2006). Changes in wind (Wang et al., 2006b), 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., 2010), 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 factors affecting dust frequency in China, but their relative importance is uncertain.

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 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., 2009e). However, projected changes in wind are lacking.

In summary, because there is high uncertainty in simulating sand and dust storms including important climate variables such as soil moisture, precipitation, and wind that affect dust storms (and because land-use changes and other non-climate factors influence dust storms substantially), there is *low confidence* in projecting future dust storm changes.

START FAQ 3.1 HERE

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, in general, has become more or less extreme. 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.

One approach for evaluating whether the climate is becoming more extreme would be to determine whether there have been changes in the typical range of variation of specific 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 temperatures in that region had become more extreme. More simply, temperature variations might be considered to be becoming more extreme if the difference between the highest and the lowest temperature observed in a year is increasing. 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, over the second half of the 20th century. On the other hand, one might conclude that daily precipitation has become more extreme because observations suggest that the magnitude of the heaviest precipitation events has increased in many parts of the world. Another approach 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. For example, an increase in the mean temperature usually results in an increase in hot extremes 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. So the answer to the question posed here would depend on the variable of interest, and on which specific measure of the extremeness of that variable is examined. As well, to provide a complete answer to the above question, one would also have to collate not just trends in single variables, but also indicators of change in complex extreme events resulting from a sequence of individual events, or the simultaneous occurrence of different types of extremes. So 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. And to make such a metric useful to more than a specific location, one would have to combine the results at many locations, each with a different perspective on what is "extreme".

Three types of metrics have been considered to avoid these problems, and thereby allow an answer to this question. One approach is to count the number of record-breaking events in a variable and to examine such a count for any trend. However, one would still face the problem of what to do if, for instance, hot extremes are setting new records, while cold extremes were not occurring as frequently as in the past. In such a case counting the number of records might not indicate whether the climate was becoming more or less extreme, rather just whether there was a shift in the mean climate. Also, the question of how to combine the numbers of record-breaking events in various extremes (e.g., daily precipitation and hot temperatures) would need to be considered. Another approach is to combine indicators of a selection of important extremes into a single index, such as the Climate Extremes Index (CEI) which measures the fraction of the area of a region or country experiencing extremes in monthly mean surface temperature, daily precipitation, and drought. The CEI, however, omits many important extremes such as tropical cyclones and tornadoes, and could, therefore, not be considered a complete index of "extremeness". Nor does it take into account complex or multiple extremes, nor the varying thresholds that relate extremes to impacts in various sectors.

A third approach to solving this dilemma arises from the fact that extremes often have deleterious 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 payout to determine if there has been an increase or decrease in that instrument. This approach would have the value that it clearly takes into account those extremes with economic consequences. But trends in such an instrument will be dominated by changes in vulnerability and exposure and it will be difficult, if not impossible, to disentangle changes in the instrument caused by non-climatic changes in vulnerability or exposure in order to leave a residual that reflects only 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 will largely reflect changes in exposure and 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.

None of the above instruments has yet been developed sufficiently as to allow us to confidently answer the question posed here. Thus we are restricted to questions about whether specific extremes are becoming more or less common, and our confidence in the answers to such questions, including the direction and magnitude of changes in specific 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.

END FAQ 3.1 HERE

START FAQ 3.2 HERE

FAQ 3.2: Can we Determine Whether Climate Change has Affected Individual Extreme Events?

A changing climate can be expected to lead to changes in climate and weather extremes. But it is challenging to associate a single extreme event with a specific cause such as increasing greenhouse gases because a wide range of extreme events could occur even in an unchanging climate, and because extreme events are usually caused by a combination of factors. Despite this, it may be possible to make an attribution statement about a specific weather event by attributing the changed probability of its occurrence to a particular cause. For instance, the likelihood of heatwaves has increased due to greenhouse warming, while the likelihood of 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.

Recent years have seen many extreme events including the extremely hot summer in Europe in 2003 and the intense North Atlantic hurricane seasons of 2004 and 2005. Can the increased atmospheric concentrations of greenhouse gases be considered the ‘cause’ of such extreme events? That is, could we say these events would NOT have occurred if CO_2 had remained at pre-industrial concentrations? 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 suggesting that the chance of such a temperature occurring in the 1950-2008 climate (assuming a stationary climate) is quite low. Is this event, therefore, an indication of a changing climate? In the CRUTEM3V global land surface temperature data set, about one in every 900 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 before the effects of greenhouse gas increases were much less pronounced.

A second complicating issue 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. So the hot 2003 European, was associated with a persistent high-pressure system (which led to clear skies and thus more solar energy received at the surface) and to dry soil (which meant that less solar energy was used for evaporation, leaving more energy to heat the soil). Another example is that hurricane genesis requires weak vertical wind shear, as well as very warm sea surface temperatures. Since some factors, but not others, may be affected by a specific cause such as increasing greenhouse gas concentrations, it is difficult to separate the human influence on a single, specific extreme event, from other factors influencing the extreme.

However, climate models can sometimes be used to identify if specific factors are changing the likelihood of the occurrence of extreme events. In the case of the 2003 European heat wave, a model experiment indicated that human influences more than doubled the likelihood of having a summer in Europe as hot as that of 2003, as discussed in AR4. 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 heatwaves or cold extremes. The same likelihood-based approach has been used to examine anthropogenic greenhouse gas contribution to flood probability.

[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).]

[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 deviations, 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.

The discussion above relates to an individual, specific occurrence of an extreme event (e.g., a single heatwave). 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) is a different matter. It is certainly feasible 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

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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 (up to 2100)
Weather and climate elements	Temperature (Section 3.3.1)	*Very likely* decrease in number of unusually cold days and nights on the global scale. *Very likely* increase in number of unusually warm days and nights on the global scale. *Likely* increase in warm spells, including heatwaves, in most regions. *Low or medium confidence* in trends in some subregions due either to lack of observations or varying signal within subregions. [Regional details in Table 3.2]	*Likely* anthropogenic influence on global trends in extreme temperature. No attribution of trends on regional scale with a few exceptions.	*Virtually certain* decrease in number of unusually cold days and nights (as defined with1961-1990 climate) on global scale. *Virtually certain* increase in number of unusually warm days and nights on global scale. *Very likely* increase in length, frequency, and/or intensity of warm spells, including heatwaves over most land areas. [Regional details in Table 3.3]
	Precipitation (Section 3.3.2)	*Likely* statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than with statistically significant decreases, but strong regional and subregional variations in the trends. [Regional details in Table 3.2]	*Medium confidence* that changes in extreme precipitation at global scale may have been anthropogenically related.	*Likely* increase in frequency of heavy precipitation events (or increase in proportion of total rainfall from heavy falls) over many areas of the globe, in particular in the high latitudes and tropical regions, and in winter in the northern mid latitudes. [Regional details in Table 3.3]
	Winds (Section 3.3.3)	*Low confidence* in trends because of insufficient evidence	*Low confidence* in the causes of trends	*Low confidence* in projections of extreme winds (with the exception of tropical cyclones)
Phenomena related to weather and climate extremes	Monsoons (Section 3.4.1)	*Low confidence* in trends because of insufficient evidence	*Low confidence* due to *insufficient evidence*	*Low confidence* in projected changes of monsoons, because of lack of consensus between climate models
	El Niño and other modes of variability (Section 3.4.2 and 3.4.3)	*Medium confidence* of past trends towards more frequent central equatorial Pacific El Niño Southern Oscillation (ENSO) 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.	*Low confidence* in projections of changes in behaviour of ENSO and other modes of variability because of insufficient congruence of model projections.
	Tropical cyclones (Section 3.4.4)	*Low confidence* of any robust long-term increases in tropical cyclone activity, after accounting for changes in observing capabilities.	*Low confidence* in attribution of changes in tropical cyclone activity to anthropogenic influences.	*Unlikely* increase in global frequency of tropical cyclones (*likely* decrease or no change). *Likely* increase in mean maximum wind speed, but possibly not in all basins. *Likely* increase in tropical cyclone-related rainfall rates.
	Extra-tropical cyclones (Section 3.4.5)	*Likely* poleward shift in extratropical cyclones. *Low confidence* in regional changes in intensity.	*About as likely as not* anthropogenic influence on poleward shift.	*Likely* impacts on regional cyclone activity but *low confidence* in detailed regional projections. A reduction in the numbers of of mid-latitude storms *is as likely as not.*

				Medium confidence in projected poleward shift of mid-latitude storm tracks.
Impacts on physical environment	Droughts (Section 3.5.1)	*Medium confidence* that some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but also opposite trends exist. [Regional details in Table 3.2]	*Medium confidence* that anthropogenic influence has contributed to the observed increases in droughts	*Medium confidence* in projected increase of duration and intensity of soil moisture and hydrological drought in some regions of the world, in particular in the Mediterranean, Central North America, Southern Mexico and Southern Africa. [Regional details in Table 3.3]
	Floods (Section 3.5.2)	*Low confidence* in changes in the magnitude and frequency in floods at the global level. Earlier occurrence of spring peak river flows in snowmelt- and glacier-fed rivers (*high confidence*),	*Low confidence* that anthropogenic warming has affected the magnitude or frequency of floods, anthropogenic influence on earlier spring peak in snow-dominated regions.	*Low confidence* in global projections of changes in flood magnitude and frequency because of insufficient literature and poor agreement between models. Increase in magnitude and/or frequency anticipated in regions where rainfall extremes are projected to increase. *Very likely* earlier spring peak flows in snowmelt and glacier-fed rivers.
	Extreme sea level and coastal impacts (Sections 3.5.3, 3.5.4, and 3.5.5)	*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 upward trends in extreme sea levels. *High confidence* that locations currently experiencing coastal erosion and inundation will continue to do so due to increasing sea level, all other factors being equal. Due to *very likely* sea ice retreat, and permafrost degradation, the frequency and magnitude of the rate of Arctic coastal erosion is *likely* to increase
	Other impacts (Sections 3.5.6, 3.5.7, and 3.5.8)	*Low confidence* of global trends in large landslides in some regions. *Likely* increased thawing of permafrost with *likely* resultant physical impacts.	*Likely* anthropogenic influence on thawing of permafrost. *Low confidence* of other anthropogenic influences because of insufficient evidence for trends in other physical impacts in cold regions.	*Medium confidence* of increase in number of shallow landslides and debris flows from recently deglaciated terrain, and that high-mountain debris flows will begin earlier in the year. *Low confidence* in projected changes in the magnitude and frequency of shallow landslides in temperate and tropical regions. *Likely* that continued permafrost degradation will further decrease the stability of rock slopes, though there is *low confidence* regarding future locations and times of large rock avalanches. *Low confidence* in projected future changes in dust activity.

Table 3.2: Regional observed changes in temperature and precipitation extremes, including dryness. See Figure 3.2 for definitions of regions.

Region and Sub-region		**Tmax [WD: warm days CD: cold days]** (using 1961-1990 extreme values as reference, e.g., 90th/10th percentile)	**Tmin [WN: warm nights CN: cold nights]** (using 1961-1990 extreme values as reference, e.g., 90th/10th percentile)	**Heat waves (HW)/ Warm spells [HWDmean/max: mean/max heat wave duration WSDI: Warm spell duration index]** (using 1961-1990 extreme values as reference)	**Heavy Precipitation (HP)**	**Dryness [CDD: consecutive dry days SM: (simulated) soil moisture PDSI: Palmer-drought severity index]**
North America	All North America	*High confidence: Likely* overall increase in HD, decrease in CD (Alexander et al., 2006).	*High confidence: Likely* overall decrease in CN, increase in WN (Alexander et al., 2006).	*Medium confidence*: Increase since 1960 (Kunkel et al., 2008).	*High confidence: Likely* increase in many areas since 1950 (Trenberth et al., 2007; Kunkel et al., 2008).	*Medium confidence:* Overall slight decrease in dryness (SM, PDSI, CDD) since 1950; regional variability and 1930s drought dominate the signal (Alexander et al., 2006; Kunkel et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).
	W. North America	*High confidence: Very likely* large increases in HD, large decreases in CD (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*High confidence: Very likely* large decreases in unusually CN, large increases in WN (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*Medium confidence*: Increase in WSDI (Alexander et al., 2006).	*Medium confidence: Spatially varying trends.* General increase, decrease in some areas, (Alexander et al., 2006).	*Medium confidence:* No overall or slight decrease in dryness (SM, PDSI, CDD) since 1950; large variability, large drought of 1930s dominates (Alexander et al., 2006; Kunkel et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).
	Central North America (CNA)	*Medium confidence: Spatially varying trends.* Small increases in HD, decreases in CD in north CNA. Small decreases in HD, increases in CD in south CNA (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*Medium confidence: Spatially varying trends.* Small decreases in CN, increases in WN in north CNA. Small increases in CN, decreases in WN in south CNA (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*Medium confidence*: *spatially varying trends.* Some areas increase, others decrease (Alexander et al., 2006).	*High confidence: Very likely* increase since 1950 (Alexander et al., 2006).	*Medium confidence*: Decrease in dryness (SM, PDSI, CDD) and increase in mean precipitation since 1950; large variability, large drought of 1930s dominates (Alexander et al., 2006; Kunkel et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).
	E. North America	*Medium confidence: Spatially varying trends.* Overall increases in WD, decreases in CD; opposite or insignificant signal in a few areas (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*Medium confidence: Spatially varying trends.* Overall small decreases in CN, overall small increases in WN in NE North America. Overall small increases in CN, overall small decreases in WN in SE North America (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*Medium confidence: Spatially varying trends.* Many areas increase, some areas decrease (Alexander et al., 2006).	*High confidence: Very likely* increase since 1950 (Alexander et al., 2006).	*Medium confidence*: Slight decrease in dryness (SM, PDSI, CDD) since 1950, large variability, large drought of 1930s dominates (Alexander et al., 2006; Kunkel et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).
	Alaska/NW Canada	*High confidence: Very likely* large increases in WD, large decreases in CD (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*High confidence: Very likely* large decreases in CN, large increases in WN (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*Low confidence*: *Insufficient evidence*	*Medium confidence:* Suggestion of increase, no significant trend (Kunkel et al., 2008).	*Medium confidence:* Inconsistent trends; increase in dryness (SM, PDSI, CDD) since 1950 in part of the region. (Alexander et al., 2006; Kunkel et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).

	E. Canada, Greenland, Iceland	*High confidence: Likely* increases in WD in some areas, decrease in others. Decreases in CD 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., 2008).	*Medium confidence:* Small increases in unusually cold nights, decreases in WN in northeastern Canada. Small decreases in CN, increases in WN in southeastern and south central Canada. (Robeson, 2004; Vincent and Mekis, 2006; Kunkel et al., 2008; Peterson et al., 2008).	*Medium confidence:* Some areas increase, most others decrease (Alexander et al., 2006).	*Medium confidence:* Increase in a few areas (Alexander et al., 2006).	*Low confidence: Insufficient evidence*
Europe	All Europe	*High confidence*: Overall *likely* increase in WD and *likely* decrease of CD over most of the continent since 1950. Strong increasing tendency in WD in most regions since 1976 onward; small or insignificant decrease in CD over same period (Alexander et al., 2006; Brown et al., 2008; see also entries for individual subregions).	*High confidence*: Overall *likely* increase in WN and *likely* decrease of CN over most of the continent since 1950. Strong increasing tendency in WN in most regions since 1976 onward; small or insignificant decrease in CN over same period (Klein Tank and Können, 2003; Alexander et al., 2006; Brown et al., 2008; see also entries for individual subregions).	*Medium confidence*: Increase of HW since 1950. Overall consistent positive trend of WSDI across Europe, but no single region with significant trends (Alexander et al., 2006). Availability of a few single studies for specific regions (see below).	*Medium confidence*: Increase in part of the region, mostly in winter, insignificant or inconsistent changes elsewhere, in particular in summer. Some inconsistencies on overall patterns between studies depending on considered indices. Most consistent signal over Central-Western Europe and European Russia (Klein Tank and Können, 2003; Haylock and Goodess, 2004; Alexander et al., 2006; Zolina et al., 2009).	*Medium confidence:* Inconsistent trends. Increase in dryness (SM, PDSI, CDD) in part of the region; insignificant, inconsistent, or no changes elsewhere. Most consistent signal for increase in dryness in Central and Southern Europe since the 1950s. No signal in Northern Europe. (Kiktev et al., 2003; Haylock and Goodess, 2004; Alexander et al., 2006; Sheffield and Wood, 2008a; Dai, 2011).
	N. Europe	*Medium confidence*: Increase in WD and decrease in CD. Consistent signals for whole region, but generally not significant at the local scale (Alexander et al., 2006). Significant increase in location parameter of yearly warmest days and insignificant trends in location parameter of yearly coldest days (Brown et al., 2008).	*Medium confidence*: Increase in WN and decrease in CN. Consistent signals over whole region but generally not significant at the local scale (Klein Tank and Können, 2003; Alexander et al., 2006; Brown et al., 2008).	*Medium confidence:* Increase of HW. Consistent tendency for increase of WSDI, but no significant trends (Alexander et al., 2006).	*Medium confidence*: Increase in winter in some areas, but often insignificant or inconsistent trends at sub-regional scale, in particular in summer (Fowler and Kilsby, 2003; Kiktev et al., 2003; Klein Tank and Können, 2003; Alexander et al., 2006; Maraun et al., 2008; Zolina et al., 2009).	*Medium confidence: Spatially varying trends.* Overall only slight or no increase in dryness (SM, PDSI, CDD), slight decrease in dryness in part of the region (Kiktev et al., 2003; Alexander et al., 2006; Sheffield and Wood, 2008a; Dai, 2011).
	Central Europe	*High confidence: Likely* overall increase in WD and *likely* decrease in CD since 1950 in most regions. Some regional and temporal variations in significance of trends. *High confidence*: *Very likely* increase in WD since 1950, 1901 and 1880 and *likely* decrease in CD since 1950 and 1901 in West-Central Europe (Alexander et al., 2006; Della-Marta et al., 2007; Laurent and Parey, 2007; Brown et al., 2008). *Medium confidence*: Lower confidence in trends in East-Central Europe compared to West-Central Europe due to lack of literature, partial lack of access to observations, overall weaker signals, and change point in trends at the end of the 1970s / beginning of 1980s. Overall tendency for increase in WD and decrease in CD, strongest increase in WD since 1976. (Alexander et al., 2006; Bartholy and Pongracz, 2007; Brown et al., 2008; Hirschi et al., 2011).	*High confidence*: *Likely* overall increase in WN and *likely* overall decrease in CN at the yearly time scale. Some regional and seasonal variations in signficance and in a few cases also the sign of the trends. *High confidence*: *Very likely* increase in WN and *very likely* decrease in CN since 1950 and 1901 in West-Central Europe (Kiktev et al., 2003; Alexander et al., 2006). *Medium confidence*: Lower confidence in trends in East-Central Europe compared to West-Central Europe due to lack of literature, partial lack of access to observations, overall weaker signals, and change point in trends at the end of the 1970s / beginning of 1980s. Overall tendency for increase in WN and decrease in CN on the yearly time scale. (Klein Tank and Können, 2003; Alexander et al., 2006; Bartholy and Pongracz, 2007; Brown et al., 2008).	*Medium confidence:* Increase in heat waves. Consistent tendency for increase of HW (WSDI) but no significant trends (Alexander et al., 2006). Significant increase in max heatwave duration HWDmax since 1880 in West-Central Europe in summer (JJA) (Della-Marta et al., 2007). Less significant signal in heatwave indices in Eastern Europe due to presence of change point (Bartholy and Pongracz, 2007; Hirschi et al., 2011).	*Medium confidence*: Increase in part of the domain, in particular in Central Western Europe and European Russia, especially in winter. Insignificant or inconsistent trends elsewhere, in particular in summer (Kiktev et al., 2003; Klein Tank and Können, 2003; Schmidli and Frei, 2005; Alexander et al., 2006; Bartholy and Pongracz, 2007; Kysely, 2009; Tomassini and Jacob, 2009; Zolina et al., 2009).	*Medium confidence: Spatially varying trends*. Increase in dryness (SM, PDSI, CDD) in part of the region but some regional variation of dryness trends and dependence of of trends on considered studies (index, time period) (Kiktev et al., 2003; Alexander et al., 2006; Bartholy and Pongracz, 2007; Sheffield and Wood, 2008a; Brazdil et al., 2009; Dai, 2011).

	S. Europe and Mediterranean	*High confidence: Likely* increase in WD and *likely* decrease in CD in most of the region. Some regional and temporal variations in significance of trends. *Likely* strongest and most significant trends in the Iberian Peninsula and Southern France (Alexander et al., 2006; Brunet et al., 2007; Della-Marta et al., 2007; Bartolini et al., 2008; Brown et al., 2008; Toreti and Desiato, 2008; Kuglitsch et al., 2010; Rodríguez-Puebla et al., 2010; Hirschi et al., 2011). *Medium confidence:* Smaller or less significant trends in Southeastern Europe and Italy due to change point in trends at the end of the 1970s / beginning of 1980s; sometimes linked with changes in sign of trends; strongest WD increase since 1976 (Bartholy and Pongracz, 2007; Bartolini et al., 2008; Toreti and Desiato, 2008; Kuglitsch et al., 2010; Hirschi et al., 2011).	*High confidence*: *Likely* increase in WN and *likely* decrease in CN in most of the region. Some regional variations in significance of trends. *Very likely* overall increase in WN and *very likely* overall decrease in CN in southwestern Europe and western Mediterranean; *likely* strongest signals in Spain and Southern France (Kiktev et al., 2003; Klein Tank and Können, 2003; Alexander et al., 2006; Brunet et al., 2007; Brown et al., 2008; Toreti and Desiato, 2008; Rodríguez-Puebla et al., 2010). *Likely* overall tendency for increase in WN and *likely* overall tendency for decrease in CN in SE Europe and eastern Mediterranean. (Kiktev et al., 2003; Klein Tank and Können, 2003; Alexander et al., 2006; Brown et al., 2008).	*High confidence: Likely* overall increase in HW in summer (JJA). Significant increase in HWDmax since 1880 in Iberian Peninsula and West-C. Europe in JJA (Della-Marta et al., 2007). Significant increase of HWDmax in Tuscany (Italy) (Bartolini et al., 2008). Significant increase in HW indices in Turkey and to a smaller extent in SE Europe and Turkey in JJA (Kuglitsch et al., 2010). Less significant signal in HW indices in SE Europe due to presence of change point in trends (Bartholy and Pongracz, 2007; Hirschi et al., 2011).	*Low confidence*: Inconsistent trends within domain and across studies. (Kiktev et al., 2003; Klein Tank and Können, 2003; Alexander et al., 2006; García et al., 2007; Pavan et al., 2008; Zolina et al., 2009; Rodrigo, 2010).	*Medium confidence:* Overall increase in dryness (SM, PDSI, CDD), but partial dependence on index and time period (Kiktev et al., 2003; Alexander et al., 2006; Sheffield and Wood, 2008a; Dai, 2011).
Africa	All Africa	*Low confidence: Insufficient evidence* (*lack of literature* in many regions)	*Low confidence: Insufficient evidence* (*lack of literature* in many regions)	*Low confidence: Insufficient evidence* (*lack of literature* for the overall continent)	*Low confidence:* Partial lack of data and literature and inconsistent patterns in existing studies (New et al., 2006; Aguilar et al., 2009; Camberlin et al., 2009).	*Medium confidence:* Overall increase in dryness (SM, PDSI); regional variability, 1970s prolonged Sahel drought dominates. (Sheffield and Wood, 2008a; Dai, 2011). No apparent continent-wide trends of change in rainfall over the 20th century, although there was a continent wide drought in 1983 and 1984 (Hulme et al., 2001). Wet season arrives 9–21 days later, large inter-annual variability of wet season start, local scale geographical variability (Kniveton et al., 2009).
	W. Africa	*Medium confidence:* Significant increase in temperature of warmest day and coldest day, significant increase in frequency of warm days, and significant decrease in frequency of cold days in western central Africa and Guinea Conakry (Aguilar et al., 2009); *lack of literature* for other parts of the region.	*Medium confidence:* Decreases in frequency of CN in western central Africa (significant) and Guinea Conakry (not significant) (Aguilar et al., 2009); *lack for literature* for other parts of the region. *High confidence: Likely* increases in WN (Trenberth et al., 2007; Aguilar et al., 2009).	*Low confidence: Insufficient evidence* (*lack of literature* for the overall continent).	*Medium confidence:* Precipitation from heavy events has decreased (Western Central Africa, Guinea Conakry) but low spatial coherence (Aguilar et al., 2009), rainfall intensity increased (New et al., 2006).	*Medium confidence:* 1970s prolonged Sahel drought dominates, conditions are still drier (SM, PDSI, precipitation anomalies) than during the humid 1950s (L'Hôte et al., 2002; Dai et al., 2004; Sheffield and Wood, 2008a; Dai, 2011). Recent years characterized by a greater interannual variability than previous 40 years, western Sahel remaining dry and the eastern Sahel returning to wetter conditions (Ali and Lebel, 2009), dry spell duration increased (New et al., 2006).

	E. Africa	*Low confidence*: *Lack of literature* for most of the domain; *Spatially non-uniform trends* in daytime temperature, some areas with cooling (King'uyu et al., 2000). *Medium confidence:* Increases in WD, decreases in CD in southern tip of domain (Trenberth et al., 2007).	*Medium confidence:* Spatially non-uniform, rise of night-time temperature at several locations, but with many coastal areas and stations near large water bodies showing a significant decrease (King'uyu et al., 2000); Decreases in CN, increases in WN, in southern tip of the domain (Trenberth et al., 2007).	*Low confidence: Insufficient evidence* (*lack of literature* for the overall continent)	*Medium confidence:* Decrease (Trenberth et al., 2007). Inter-annual variations in the onset date of the rainy season have had the biggest impact on seasonal rains (Camberlin et al., 2009).	*Low confidence: Spatially varying trends* in dryness (SM, PDSI) (Sheffield and Wood, 2008a; Dai, 2011).
	S. Africa	*Medium confidence:* Increases in WD, decreases in CD (Trenberth et al., 2007).	*Medium confidence:* Decreases in CN, increases in WN (Alexander et al., 2006). Regional variations, increase at several locations, but with many coastal areas and stations near large water bodies showing a significant decrease (King'uyu et al., 2000).	*Low confidence: Insufficient evidence* (*lack of literature* for the overall continent)	*Medium confidence:* Rainfall intensity increased (Kruger, 2006; New et al., 2006; Trenberth et al., 2007).	*Medium confidence:* Slight dry spell duration increase (Alexander et al., 2006; Kruger, 2006; New et al., 2006) General increase in dryness (SM, PDSI) (Sheffield and Wood, 2008a; Dai, 2011).
	Sahara	*Low confidence: Lack of literature.*	*Medium Confidence:* Increases in unusually WN (Trenberth et al., 2007). *Lack of literature* on trends in unusually CN.	*Low confidence: Insufficient evidence* (*lack of literature* for the overall continent)	*Low confidence: Insufficient evidence*	*Low confidence:* Limited data, spatial variation of the trends (Dai, 2011).
Central and South America	All SA	*Low confidence: Insufficient evidence*	*Low confidence: Insufficient evidence*	*Low confidence: Insufficient evidence*	*Low confidence: Insufficient evidence*	*Low confidence: Spatially varying trends, Inconsistencies between studies* (Sheffield and Wood, 2008a; Dai, 2011).
	C. America & Northern SA	*Medium confidence:* Increases in WD, decreases in CD (Aguilar et al., 2005; Alexander et al., 2006; Brown et al., 2008).	*Medium confidence:* Decreases in CN, increases in WN (Aguilar et al., 2005; Alexander et al., 2006; Brown et al., 2008).	*Low confidence: Spatially varying trends.* A few areas increase, a few others decrease (Aguilar et al., 2005; Alexander et al., 2006).	*Medium confidence: Spatially varying trends.* Increase in many areas, decrease in a few areas, (Aguilar et al., 2005; Alexander et al., 2006).	*Low confidence: Spatially varying trends, Inconsistencies in trends* in dryness (SM, PDSI, CDD). (Aguilar et al., 2005; Sheffield and Wood, 2008a; Dai, 2011).
	Amazon	*Low confidence: Insufficient evidence*.	*Low confidence: Insufficient evidence* (Alexander et al., 2006; Dufek et al., 2008).	*Low confidence:* Insufficient evidence	*Medium confidence: Spatially varying trends.* Increase in many areas, decrease in a few areas (Alexander et al., 2006; Haylock et al., 2006).	*Low confidence: Spatially varying trends, Mixed results.* Slight decrease of CDD (Dufek et al., 2008). Tendency to decreased dryness in much of region, but some opposite trends and inconsistencies between studies (Sheffield and Wood, 2008a; Dai, 2011).
	Northeastern Brazil	*Medium confidence:* Increases in WD (Silva and Azevedo, 2008).	*Medium confidence:* Increases in WN (Silva and Azevedo, 2008).	*Low confidence: Insufficient evidence*	*Medium confidence:* Increase in many areas, decrease in a few areas, (Alexander et al., 2006; Haylock et al., 2006; Santos and Brito, 2007; Silva and Azevedo, 2008; Santos et al., 2009).	*Low confidence: Spatially varying trends.* Inconsistent trends in CDD (Santos and Brito, 2007; Dufek et al., 2008; Silva and Azevedo, 2008; Santos et al., 2009).Inconsistent trends in dryness (SM, PDSI) between studies (Sheffield and Wood, 2008a; Dai, 2011).

	SE South America	*Medium confidence: Spatially varying trends.* Increases in WD in some areas, decrease in others. Decreases in CD in some areas, increase in others, (Rusticucci and Barrucand, 2004; Vincent et al., 2005; Alexander et al., 2006; Brown et al., 2008; Rusticucci and Renom, 2008; Marengo et al., 2009b).	*Medium confidence:* Decreases in CN, increases in WN (Rusticucci and Barrucand, 2004; Vincent et al., 2005; Alexander et al., 2006; Brown et al., 2008; Rusticucci and Renom, 2008; Marengo et al., 2009b).	*Low confidence: Spatially varying trends.* Some areas increase, others decrease (Alexander et al., 2006).	*Medium Confidence:* Increase (Alexander et al., 2006; Dufek et al., 2008; Sugahara et al., 2009; Penalba and Robeldo, 2010).	*Low Confidence:* Slight increase in dryness, large variability (Haylock et al., 2006; Dufek and Ambrizzi, 2008; Dufek et al., 2008; Penalba and Robeldo, 2010; Llano and Penalba, 2011). Decrease in dryness (SM, PDSI) in much of region (Sheffield and Wood, 2008a; Dai, 2011).
	W. Coast SA	*Medium confidence:* Increases in WD in some areas, decrease in others. Decreases in CD in some areas, increase in others, (Rosenbluth et al., 1997; Vincent et al., 2005; Alexander et al., 2006).	*Medium confidence:* Decreases in CN, increases in WN (Rosenbluth et al., 1997; Vincent et al., 2005; Alexander et al., 2006).	*Low confidence: Insufficient evidence*	*Medium confidence: Spatially varying trends.* Decrease in many areas, increase in a few areas (Alexander et al., 2006; Haylock et al., 2006).	*Medium Confidence:* Slight increased dryness (SM, PDSI, CDD) in most areas (Dufek et al., 2008; Sheffield and Wood, 2008a; Dai, 2011).
Asia	All Asia	*Medium confidence:* Increase in WD, decrease in CD	*Medium confidence:* Increase in WN, decrease in CN	*Low confidence: Insufficient evidence*	*Low confidence: Insufficient evidence*	*Low confidence: Spatially varying trends*. Some areas present consistent increases, respectively decreases, in dryness (SM, PDSI, CDD) (Alexander et al., 2006; Sheffield and Wood, 2008a; Dai, 2011) .
	N. Asia	*High confidence: Likely* increases in WD, decreases in CD (Alexander et al., 2006).	*Medium confidence:* Decreases in CN, increases in WN (Alexander et al., 2006; Trenberth et al., 2007).	*Medium confidence: Spatially varying trends.* General increase, decrease in a few areas (Alexander et al., 2006).	*Medium confidence:* Increase (Trenberth et al., 2007). Some increase in western Russia, especially in winter (DJF), 1950-2000 (Zolina et al., 2009).	*Low confidence: Spatially varying trends.* Tendency for increased dryness (SM, PDSI, CDD) in central and northeastern N. Asia, other areas decreased dryness (Alexander et al., 2006; Sheffield and Wood, 2008a; Dai, 2011).
	Central Asia	*High confidence: Likely* increases in WD, decreases in CD (Alexander et al., 2006; Trenberth et al., 2007).	*High confidence:* Decreases in CN, increases in WN (Alexander et al., 2006; Trenberth et al., 2007).	*Medium confidence:* Increase in a few areas, insufficient evidence elsewhere (Alexander et al., 2006).	*Low confidence: Spatially varying trends.* Increase in a few areas, decrease in a few areas. (Alexander et al., 2006).	*Low confidence: Spatially varying trends* in dryness (SM, PDSI, CDD); partial lack of coverage in some studies (Alexander et al., 2006; Sheffield and Wood, 2008a; Dai, 2011).
	East Asia	*High confidence: Likely* increases in WD, decreases in CD (Trenberth et al., 2007; Ding et al., 2010).	*Medium confidence:* Decreases in CN, increases in WN (Alexander et al., 2006).	*Medium confidence:* Increase in warm season heat waves in China (Ding et al., 2010), but decline in all warm spells (Alexander et al., 2006).	*Low confidence: Spatially varying trends.* Increase in a few areas, decrease in a few areas (Alexander et al., 2006).	*Medium confidence:* Overall tendency for increased dryness (SM, PDSI, CDD); few areas with opposite trends (Alexander et al., 2006; Sheffield and Wood, 2008a; Dai, 2011).
	S.E. Asia	*Medium confidence:* Increases in WD, decreases in CD, northern part (Alexander et al., 2006).	*Medium confidence:* Decreases in CN, increases in WN, northern part. (Alexander et al., 2006).	*Low confidence: Insufficient evidence*	*Low confidence: Spatially varying trends.* Some areas increase, some areas decrease (Alexander et al., 2006).	*Low confidence: Spatially varying trends, Inconsistent trends* in dryness (SM, PDSI) between studies (Sheffield and Wood, 2008a; Dai, 2011).

	S. Central Asia	*Medium confidence:* Increase in WD and decrease in CD (Alexander et al., 2006).	*Medium confidence:* Decreases in CN, increases in WN (Alexander et al., 2006).	*Low confidence*: *Insufficient evidence*	*Low Confidence:* Mixed signal in India (Alexander et al., 2006).	*Low confidence: Inconsistent signal for different studies and indices.* Decrease in CDD over India (Alexander et al., 2006). Increased dryness (SM, PDSI) in central India (Sheffield and Wood, 2008a; Dai, 2011).
	Tibetan Plateau	*High confidence: Likely* increase in WD and decrease in CD (Alexander et al., 2006).	*High confidence: Likely* decreases in CN, increases in WN (Alexander et al., 2006).	*Low confidence:* Increase in a few areas, insufficient evidence elsewhere (Alexander et al., 2006).	*Low confidence: Insufficient evidence.*	*Low confidence: Lack of studies.* Tendency to decreased dryness (PDSI, SM) in Dai (2011).
	W. Asia	*High confidence: More likely than not* decrease in CD and *very likely* increase in WD (Choi et al., 2009; Rahimzadeh et al., 2009; Rehman, 2010).	*High confidence: Likely* decrease in CN and likely increase in WN (Choi et al., 2009; Rehman, 2010).	*Medium confidence:* Increase in warm spells (Alexander et al., 2006).	*Medium confidence:* decrease in heavy precipitation events. (Kwarteng et al., 2009; Rahimzadeh et al., 2009).	*Low confidence:* Mixed results. (Kwarteng et al., 2009; Rahimzadeh et al., 2009).
Australia/New Zealand	N. Australia	*High confidence: Very likely* increases in WD, decreases in CD. Weaker trends in northwest (Alexander et al., 2006; Trenberth et al., 2007).	*High confidence: Very likely* decreases in CN, increases in WN (Alexander et al., 2006).	*Low confidence:* Insufficient studies for assessment	*Low confidence:* Insufficient studies for assessment.	*Medium confidence:* Decrease in dryness (SM, PDSI) in northwest since mid-20th century (Sheffield and Wood, 2008a; Dai, 2011).
	S. Australia/NZ	*High confidence: Very likely* increases in WD, decreases in CD (Alexander et al., 2006; Trenberth et al., 2007). NZ positive trends vary across country, related to circulation changes (Chambers and Griffiths, 2008; Mullan et al., 2008).	*High confidence: Very likely* decreases in CN, increases in WN (Alexander et al., 2006). General decrease in frosts in NZ but trends vary across country, related to circulation changes (Chambers and Griffiths, 2008; Mullan et al., 2008).	*Medium confidence:* increase in warm spells across southern Australia (Alexander and Arblaster, 2009).	*High confidence: Likely* increase in heavy precipitation in many areas, except where mean precipitation has decreased (CSIRO and Bureau of Meteorology, 2007; Gallant et al., 2007; Alexander and Arblaster, 2009). NZ trends are positive in western N. and S. Islands and negative in east of country, and are strongly correlated with changes in mean rainfall (Mullan et al., 2008).	*Medium confidence:* Increase in dryness (SM, PDSI, CDD) in southeastern part and southwestern tip of continent since mid-20th century; decrease in dryness in central part of continent (Alexander et al., 2006; Sheffield and Wood, 2008a; Dai, 2011).

Table 3.3: Projected regional changes in temperature and precipitation (including dryness) extremes. See Figure 3.2 for definitions of regions. Projections are for the end of the 21st century vs end of the 20th century (i.e., 1961-1990 or 1980-1999 vs 2071-2100 or 2080-2099) and for the A2/A1B emissions scenario. Codes for the source of modelling evidence: G: Based on GCM simulations. **G**: multi-GCM. R: Based on RCM simulations. **R**: multi-GCM. R: multi-RCM. T06 stands for Tebaldi et al. (2006), SW08 stands for Sheffield and Wood (2008b), and OS11 stands for Orlowsky and Seneviratne (2011).

Region and Sub-Region		**Tmax [WD: warm days CD: cold days] (using 1961-1990 extreme values as reference, e.g., 90th/10th percentile)**		**Tmin [WN: warm nights CN: cold nights] (using 1961-1990 extreme values as reference, e.g., 90th/10th percentile)**		**Heat waves (HW) / Warm spells [HWDmean/max: mean/max heat wave duration WSDI: Warm spell duration index] (using 1961-1990 extreme values as reference)**		**Heavy precipitation (HP) [HPD: heavy precipitation days, e.g., precipitation > 95th percentile %DP10: percentage of days with precipitation > 10mm HPC: heavy precipitation contribution e.g., fraction from precipitation > 95th percentile] (using 1961-1990 extreme values as reference except in case of %DP10)**		**Dryness [CDD: consecutive dry days SM: (simulated) soil moisture PDSI: Palmer-drought severity index]**	
North America	All North America	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease in all regions (Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; OS11). *Medium confidence*: Largest increases of HD in summer and fall particularly over the US; largest decrease of CD in Canada in fall and winter (OS11).	**G**	*High confidence*: WN *very likely* to increase & CN *very likely* to decrease over all regions (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; OS11). *Medium confidence :* Largest increase in WN and decrease in CN in summer, particularly in the US (OS11).	**G**	*High confidence: Likely* more frequent and longer heat waves & warm spells over all regions (T06; Christensen et al., 2007; Karl et al., 2008; OS11).	**G**	*Low to high confidence: Likely* increase in HPD and HPC over Canada and Alaska; smaller and less consistent changes in south, but inconsistencies between %DP10 (decreases in winter spring) and other indices (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; OS11).	**G**	*Low to medium confidence. Medium confidence* regarding increase in CDD, and SM drought in Texas and N. Mexico (T06; SW08; OS11). *Low confidence*: Inconsistent change in other regions (SM, CDD) (T06; SW08; OS11).	**G**
	W. North America	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease in all seasons (Christensen et al., 2007; Karl et al., 2008; Clark et al., 2011; OS11). *Medium confidence*: Overall weaker signal in spring and winter for both CD and HD (OS11).	**G**	*High confidence*: WN *very likely* to increase & CN *very likely* to decrease (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; OS11). *Medium confidence:* Largest WN increases and CN decreases in summer (OS11).	**G**	*High confidence: Likely* more frequent and longer heat waves & warm spells (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; Clark et al., 2011; OS11).	**G**	*Low to medium confidence:* Increase of HPD/HPC over northern part of domain (Canada); no signal or inconsistent signal over southern part of domain (T06; OS11).	**G**	*Low confidence:* inconsistent signal in CDD and SM changes (T06; SW08; OS11).	**G**
	Central North America	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease in all seasons (Christensen et al., 2007; Karl et al., 2008; Clark et al., 2011; OS11). *Medium confidence*: Weaker signal for CD in spring and winter (OS11).	**G**	*High confidence*: WN *very likely* to increase & CN *very likely* to decrease (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; OS11).	**G**	*High confidence: Likely* more frequent and longer heat waves & warm spells. (T06; Christensen et al., 2007; Karl et al., 2008; Clark et al., 2011; OS11).	**G**	*Low confidence*: Inconsistent or no signal (T06; OS11).	**G**	*Medium confidence:* Increase in CDD and decrease of SM in southern part of the domain (SW08; OS11); Low confidence: inconsistent signal elsewhere (OS11).	**G**
	E. North America	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease in all seasons (Christensen et al., 2007; Karl et al., 2008; Clark et al., 2011; OS11). *Medium confidence*: Largest HD increase in summer and fall; weaker CD decrease in spring (OS11).	**G**	*High confidence*: WN *very likely* to increase & CN *very likely* to decrease (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; OS11). *Medium confidence:* Largest WN increases and CN decreases in summer (OS11).	**G**	*High confidence: Likely* more frequent and longer heat waves & warm spells (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; Clark et al., 2011; OS11).	**G**	*Medium confidence*: Increase of HPD/HPC in northern part of domain but no signal or inconsistent signal in southern part (T06; OS11).	**G**	*Low confidence:* inconsistent signal in CDD, some consistent decrease of SM (SW08; OS11).	**G**

	Alaska / NW Canada	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease (Christensen et al., 2007; Karl et al., 2008; OS11). *Medium confidence*: strongest increase of HD in the fall (OS11).	G	*High confidence*: WN *very likely* to increase & CN *very likely* to decrease (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; OS11).	G	*High confidence: Likely* more frequent and longer heat waves & warm spells (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; Karl et al., 2008; OS11).	G	*High confidence*: *Likely* increase of HPD and HPC (T06; Kharin et al., 2007; OS11).	G	*Low confidence:* inconsistent signal in change of CDD and SM (T06; SW08; OS11).	G
	E. Canada, Greenland, Iceland	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease (Christensen et al., 2007; Karl et al., 2008; OS11). *Medium confidence*: strongest increase of HD in fall and winter (in summer in Greenland), weakest in spring, weaker increase of CD in summer (OS11).	G	*High confidence*: WN *very likely* to increase & CN *very likely* to decrease (T06; Christensen et al., 2007; Kharin et al., 2007; Meehl et al., 2007; OS11).	G	*High confidence: Likely* more frequent and longer heat waves & warm spells (T06; OS11).	G	*High confidence*: *Likely* increase of HPD and HPC (T06; Kharin et al., 2007; OS11).	G	*Low confidence:* inconsistent signal in CDD and/or SM changes (T06; SW08; OS11).	G
Europe	All Europe	*High confidence*: HD *very likely* to increase – largest increases in summer and C/S Europe & smallest in N Europe (Scandinavia) (Goubanova and Li, 2007; Kharin et al., 2007; Kjellstrom et al., 2007; OS11; Koffi and Koffi, 2008) and cold days *very likely* to decrease (OS11). *Medium confidence:* Changes in higher quantiles of Tmax generally greater than changes in lower quantiles of Tmax in summer in Central Europe and Mediterranean (Diffenbaugh et al., 2007; Kjellstrom et al., 2007; Fischer and Schär, 2009; Fischer and Schär, 2010; OS11).	**G** **R**	*High confidence*: CN *very likely* to decrease – largest decreases in winter & E Europe & Scandinavia (Goubanova and Li, 2007; Kjellstrom et al., 2007; Sillmann and Roeckner, 2008).WN *very likely* to increase (T06; Kharin et al., 2007; OS11).	**G** **R**	*High confidence:* HWD *likely* to increase (also increases in intensity & frequency) but little change over Scandinavia (Beniston et al., 2007; Christensen et al., 2007; Kysely and Beranova, 2009; Clark et al., 2011; OS11).	**G** **R**	*Low to high confidence, depending on regions: Very likely* increases in HPD, %DP10, and decreases in return periods of long (5-day) and short (1-day) events in N. Europe particularly in winter; lower confidence in changes in C. Europe and the Mediterranean (T06; Beniston et al., 2007; Fowler et al., 2007; Kharin et al., 2007; Sillmann and Roeckner, 2008; Kendon et al., 2010; OS11). *Likely* increase in HPC in some regions (Boberg et al., 2009; Kendon et al., 2010). *Likely* greater changes in extremes than mean in many regions.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., 2007; Haugen and Iverson, 2008; May, 2008; Kysely and Beranova, 2009).	**G** **R**	*Medium confidence:* European area affected by stronger dryness (reduced SM and CDD) with largest and most consistent changes in Mediterranean Europe (T06; Burke and Brown, 2008; May, 2008; SW08; Sillmann and Roeckner, 2008; OS11).	**G** R

	N. Europe	*High confidence: Very Likely* increase in frequency of HD, but smaller than in Central and Southern Europe (Fischer and Schär, 2010; OS11). *Very likely* decrease in CD (OS11). *Medium confidence:* Changes in lower quantiles of Tmax generally greater than for changes in higher quantiles of Tmax in fall, winter and spring in Scandinavia and Northeastern Europe (OS11).	**G R**	*High confidence*: CN *very likely* to decrease (Goubanova and Li, 2007; Kjellstrom et al., 2007; Sillmann and Roeckner, 2008); WN *very likely* to increase (T06; OS11). *Medium confidence:* Changes in lower quantiles of Tmin generally greater than changes in higher quantiles of Tmin in Scandinavia and Northeastern Europe (Goubanova and Li, 2007; Kjellstrom et al., 2007; OS11).	**G R**	*High confidence*: HWD *likely* to increase, but summer increases smaller than in S Europe and little change over Scandinavia (Beniston et al., 2007; Kysely and Beranova, 2009; Clark et al., 2011; OS11).	**G R**	*High confidence: Very likely* increases in HP (intensity and frequency) and %DP10 north of 45N in winter (Frei et al., 2006; T06; Beniston et al., 2007; Kendon et al., 2008; OS11).	**G** R	*Medium confidence*: No major changes in dryness (CDD, SM deficit) in Northern Europe (T06; SW08; Sillmann and Roeckner, 2008; OS11).	**G**
	Central Europe	*High confidence: Very likely* increase in frequency and intensity of HD (Fischer and Schär, 2010; OS11) and decrease in frequency of CD (OS11). *Medium confidence:* Changes in higher quantiles of Tmax much larger than changes in lower quantiles of Tmax in summer; results in very large increase in Tmax variability (Seneviratne et al., 2006; Diffenbaugh et al., 2007; Kjellstrom et al., 2007; Fischer and Schär, 2009; Fischer and Schär, 2010; OS11).	**G R**	*High confidence*: CN *very likely* to decrease (Goubanova and Li, 2007; Kjellstrom et al., 2007; Sillmann and Roeckner, 2008); WN *very likely* to increase (T06; OS11).	**G** R	*High confidence*: HWD *likely* to increase (Beniston et al., 2007; Kysely and Beranova, 2009; Fischer and Schär, 2010; OS11).	**G R**	*High confidence: Likely* increases in HP (intensity and frequency) in large part of the region in winter (Frei et al., 2006; Beniston et al., 2007; Kendon et al., 2008). *Medium confidence:* Inconsistent evidence for summer: increase in HP in summer evident in RCMs (Christensen and Christensen, 2003; Frei et al., 2006) vs no signal in GCMs (OS11).	**G R**	*Medium confidence:* Increase in dryness (CDD, SM) in Central Europe (Seneviratne et al., 2006; T06; OS11). *Medium confidence:* Increase in short-term droughts (SW08).	**G** R
	S. Europe and Mediterranean	*High confidence: Very likely* increase in frequency and intensity of HD (Fischer and Schär, 2009; Giannakopoulos et al., 2009; Fischer and Schär, 2010; OS11) and decrease in frequency of cold days (OS11). *High confidence*: Number of days with combined hot summer days (>35°C) and tropical nights (>20°C) *very likely* to increase (Fischer and Schär, 2010). *Medium confidence:* Changes in higher quantiles of Tmax greater than changes in lower quantiles of Tmax in summer (Diffenbaugh et al., 2007; Kjellstrom et al., 2007; Fischer and Schär, 2009; Fischer and Schär, 2010; OS11).	**G R**	*High confidence*: CN *very likely* to decrease (Goubanova and Li, 2007; Kjellstrom et al., 2007; Sillmann and Roeckner, 2008). *High confidence*: WN *very likely* to increase (T06; Sillmann and Roeckner, 2008; Giannakopoulos et al., 2009; OS11). *High confidence*: Tropical nights *very likely* to increase (Sillmann and Roeckner, 2008). Number of days with combined hot summer days (>35°C) and tropical nights (>20°C) *very likely* to increase (Fischer and Schär, 2010). *Medium confidence*: Changes in higher quantiles of Tmin generally greater than changes in lower quantiles of Tmin in summer in the Mediterranean (Diffenbaugh et al., 2007; OS11).	**G R**	*High confidence: Likely* increase in HWD (also increases in intensity and frequency) - *likely* 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; OS11; Clark et al., 2011).	**G R**	*Low confidence*: Inconsistent change in HP intensity and %D10, depends on region and season; increase in HP intensity in all seasons except summer over parts of the region, but decrease in other parts, e.g., Iberian Peninsula (T06; Goubanova and Li, 2007; Giorgi and Lionello, 2008; Giannakopoulos et al., 2009).	**G R**	*Medium confidence:* Increase in dryness (CDD, SM) in Mediterranean (T06; Beniston et al., 2007; SW08; Giannakopoulos et al., 2009; OS11).	**G R**

Africa	All Africa	*High confidence*: HD *likely* to increase & CD *likely* to decrease in all regions (Kharin et al., 2007; OS11). *Medium confidence:* Increase in HD largest in summer and fall (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; Kharin et al., 2007; OS11) and CN *likely* to decrease (OS11).	**G**	*High confidence: Likely* increase of HWD but weaker seasonal signal and ~0-30S (Clark et al., 2006; TS06; OS11).	**G**	*Low to high confidence*: Inconsistent change or no signal in HP indicators across much of continent (T06; OS11). Strongest and most consistent signal is *very likely* increase in HP in E. Africa (TS06; OS11; Shongwe et al., 2011).	**G**	*Low to medium confidence*: *Low confidence* in most regions, *medium confidence* of increase in dryness (CDD, SM) in South Africa except eastern part (T06; SW08; OS11).	**G**
Africa	W. Africa	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	**G**	*High confidence: Likely* increase of HWD but weaker seasonal signal and ~0-30S (Clark et al., 2006; TS06; OS11).	**G**	*Low to medium confidence*: Slight or no change in HP indicators, inconsistent sign within region; low agreement in tropical part of region (T06; OS11).	**G**	*Low confidence*, inconsistent signal of change in CDD and SM (T06; OS11).	**G**
Africa	E. Africa	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; OS11) and CN likely to decrease (OS11).	**G**	*High confidence: Likely* increase of HWD but weaker seasonal signal and ~0-30S (Clark et al., 2006; TS06; OS11).	**G**	*High confidence*: *Likely* increase in HPD and HPC (TS06; OS11; Shongwe et al., 2011).	**G**	*Low confidence*, inconsistent signal of change in CDD and SM (TS06; OS11; Shongwe et al., 2011).	**G**
Africa	S. Africa	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	**G**	*High confidence: Likely* increase of HWD but weaker seasonal signal (Clark et al., 2006; TS06; OS11).	**G**	*Low confidence*: Lack of agreement/signal in %DP10 and other HP indicators for the region as a whole (T06; OS11). Some evidence of increased HP intensity in the SE (Hewitson and Crane, 2006; Rocha et al., 2008; Shongwe et al., 2009).	**G**	*Medium confidence*: dryness (CDD, SM) increase, except Eastern part (T06; Shongwe et al., 2009; OS11).	**G**
Africa	Sahara	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	**G**	*High confidence: Likely* increase of HWD but weaker seasonal signal (T06; OS11).	**G**	*Low confidence*: Low agreement/no signal in %DP10 and other HP indicators (T06; OS11).	**G**	*Low confidence*, inconsistent signal of change in CDD and SM (T06; OS11).	**G**
Central and South America	All South America	*High confidence*: HD *likely* to increase & CD *likely* to decrease in all regions (Kharin et al., 2007; OS11).	**G**	*High confidence*: WN *likely* to increase (T06; Kharin et al., 2007; OS11) and CN *likely* to decrease (OS11).	**G**	*Medium to high confidence: Likely* increases of HWDmax on annual time scale in most regions of South America; only *medium confidence* in HWDmax increase in Southeastern South America (T06; OS11). *Medium confidence:* Changes in HWDmean generally smaller and less consistent than HWDmax changes (OS11).	**G**	*Low to medium confidence*: Inconsistent sign of change of HP indicators across continent; some regions with model agreement (T06; OS11).	**G**	*Low to medium confidence*: inconsistent signal except for dryness increase (CDD and SM) in Northeastern Brazil and Central America (SW08; OS11).	**G**
Central and South America	Central America and northern South	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	**G**	*High confidence: Likely* increases of HWDmax on annual time scale (T06; OS11).	**G**	*Low confidence*: *Lack of agreement* between models regarding changes in %DP10 and other HP indicators (Kamiguchi et al., 2006; T06; Campbell et al., 2011; OS11).	**G** R	*Low to medium confidence:* increase in dryness (CDD, SM) in Central America, inconsistent signal in CDD and SM in northern South America (Kamiguchi et al., 2006; T06; Campbell et al., 2011; OS11).	**G** R

	Amazon	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: *Very likely* increase of WN (T06; Uchiyama et al., 2006; Marengo et al., 2009a; OS11) and CN *likely* to decrease (OS11).	**G** R	*High confidence: Likely* increases of HWDmax on annual time scale (T06; Uchiyama et al., 2006; OS11).	**G**	*Medium confidence : Increase of precip >95th* (Kamiguchi et al., 2006; T06; Marengo et al., 2009a; Sorensson et al., 2010; OS11).	**G** R	*Low confidence:* inconsistent signal SM (SW08; OS11) and inconsistent signal in CDD (Kamiguchi et al., 2006; T06; Marengo et al., 2009a; Sorensson et al., 2010; OS11).	**G** R
	Northeastern Brazil	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence: Likely* increase of WN (T06; Uchiyama et al., 2006; Marengo et al., 2009a; OS11) and CN *likely* to decrease (OS11).	**G** R	*High confidence: Likely* increases of HWDmax on annual time scale (T06; Uchiyama et al., 2006; OS11).	**G**	*Low confidence: Slight or no change in %DP1 and other HP indicators* (Kamiguchi et al., 2006; T06; Marengo et al., 2009a; Sorensson et al., 2010; OS11).	**G** R	*Medium confidence:* Dryness (CDD, SM deficit) increase (Kamiguchi et al., 2006; T06; SW08; Marengo et al., 2009a; Sorensson et al., 2010; OS11).	**G** R
	Southeastern South America	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence: Very likely* increase of WN (T06; Uchiyama et al., 2006; Marengo et al., 2009a; OS11) and CN *likely* to decrease (OS11).	**G** R	*Medium confidence*: Weak tendency for increase of HWDmax, but robust sign across majority of models (T06; Uchiyama et al., 2006; OS11).	**G**	*Medium confidence:* Increase of %DP10, precipitation intensity and precip>95[th] (Kamiguchi et al., 2006; T06; Marengo et al., 2009a; Nunez et al., 2009; OS11).	**G** R	*Low confidence*: inconsistent signal in SM (OS11). *Low confidence* inconsistent signal in CDD (Kamiguchi et al., 2006; T06; Marengo et al., 2009a; Sorensson et al., 2010; OS11).	**G** R
	Western Coast of South America	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence: Likely* increase of WN (T06; Uchiyama et al., 2006; Marengo et al., 2009a; OS11) and CN *likely* to decrease (OS11).	**G** R	*High confidence: Likely* increases of HWDmax on annual time scale (T06; OS11).	**G**	*Medium confidence:* Increase in %DP10, precip>95[th] and other HP indicators in the tropics. *Low confidence* for the extratropics (Kamiguchi et al., 2006; T06; Marengo et al., 2009a; Sorensson et al., 2010; OS11).	**G** R	*Low confidence:* inconsistent change of SM across domain (OS11) ,decrease in CDD in the tropics and an increase in the extratropics (Kamiguchi et al., 2006; T06; Marengo et al., 2009a; Sorensson et al., 2010; OS11). *Medium confidence:* Increase in CDD and decrease in SM in south-west South America (SW08; OS11).	**G** R

Asia	All Asia	*High confidence*: HD *likely* to increase & CD *likely* to decrease in all regions (Kharin et al., 2007; OS11).	**G**	*High confidence*: WN *likely* to increase (T06; Kharin et al., 2007; OS11) and CN *likely* to decrease (OS11).	**G**	*Low to high confidence:* Increases of HWDmax *likely* in most regions (continent) on the annual time scale; inconsistent signal in Indonesia, Philippines, Malaysia, Papua New Guinea and neighbouring islands (T06; OS11). Weaker signals on the seasonal time scale over continent (OS11).	**G**	*Low to high confidence* depending on region: *High confidence* regarding *likely* increase of HP in N. Asia, *Medium confidence* regarding increase of HP in SE. Asia and E Asia and *Low confidence* regarding increase of HP in S and W Asia and Tibetan plateau (T06; OS11).	**G**	*Low confidence:* Inconsistent change in CDD and SM between models in large part of domain; (T06; OS11).	**G**
	N. Asia	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	**G**	*High confidence: Likely* increases of HWD (T06; OS11).	**G**	*High confidence*: *Likely* increase of HP (T06; OS11) including more frequent & intense HPD over most regions (Emori and Brown, 2005; Kamiguchi et al., 2006).	**G**	*Low confidence:* Inconsistent change in dryness (CDD, SM) between models in large part of domain; (T06; SW08; OS11).	**G**
	Central Asia	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	**G**	*High confidence: Likely* increases of HWD (T06; OS11).	**G**	*Low confidence*: Inconsistent signal in models regarding changes in HP (T06; OS11).	**G**	*Low confidence*: Inconsistent signals across indices (CDD, SM) (T06; SW08; OS11).	**G**
	East Asia	*High confidence*: HD *likely* to increase & CD *likely* to decrease across the region (Clark et al., 2011; OS11), including in Korea (Boo et al., 2006; Im and Kwon, 2007; Im et al., 2008; Koo et al., 2009; Im et al., 2011).	**G** R	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11), including in Korea (Boo et al., 2006; Koo et al., 2009; Im et al., 2011).	**G** R	*High confidence: Likely* increases of HWD (T06; Clark et al., 2011; OS11).	**G**	*Medium confidence*: Increases in HP (less consistent in %DP10 than other indicators) across the region (T06; OS11), including increase in Japan and Korea (Emori and Brown, 2005; Kimoto et al., 2005; Boo et al., 2006; Kamiguchi et al., 2006; Kusunoki and Mizuta, 2008; Kitoh et al., 2009; Su et al., 2009; Kim et al., 2010; Im et al., 2011).	**G** R	*Low confidence:* Inconsistent signal across indices (CDD, SM) (T06; SW08; OS11).	**G**
	S.E. Asia	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	**G**	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	**G**	*Low to high confidence:* Inconsistent signal in Indonesia, Philippines, Malaysia, Papua New Guinea and neighbouring islands; *likely* increases of HWDmax on the annual time scale over continental (T06; OS11).	**G**	*Medium confidence*: Inconsistent signal in change of %DP10 across models. (T06; OS11) but more frequent & intense HPD suggested by other indicators over most regions especially non-continental parts (Emori and Brown, 2005; Kamiguchi et al., 2006; OS11).	**G**	*Low confidence:* inconsistent signal of change in CDD and/or SM (T06; SW08; OS11).	**G**
	S. Asia	*High confidence*: HD *likely* to increase & CD *likely* to decrease (Kumar et al., 2006; Rajendran and Kitoh, 2008; OS11).	**G** R	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11). *Medium confidence:* Extreme nighttime temperature warms faster than daytime (Kumar et al., 2006).	**G** R	*High confidence: Likely* increases of HWDmax on annual time scale (T06; OS11). *Medium confidence:* Weaker signal than in most other land regions for HWDmax and weaker signal for HWDmean; less robust signal on seasonal time scale (OS11).	**G**	*Low confidence*: *slight or no increase in %DP10* (T06; OS11). *Low confidence:* More frequent & intense HPD over parts of S. Asia (Emori and Brown, 2005; Kamiguchi et al., 2006; Kharin et al., 2007; Rajendran and Kitoh, 2008).	**G** R	*Low confidence:* inconsistent signal of change in CDD and SM (T06; SW08; OS11).	**G**

	W. Asia	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11).	G	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	G	*High confidence: Likely* increases of HWD (T06; OS11).	G	*Low confidence*: Inconsistent signal of change in HP (T06; OS11).	G	*Low confidence:* inconsistent signal of change in CDD and SM (T06; SW08; OS11).	G
	Tibetan Plateau	*High confidence*: HD *likely* to increase & CD *likely* to decrease (OS11). *Medium confidence*: Large changes both in lower and higher quantiles of Tmax compared to other Asian regions but only for higher quantiles in winter (OS11).	G	*High confidence*: WN *likely* to increase (T06; OS11) and CN *likely* to decrease (OS11).	G	*High confidence: Likely* increases of HWD (T06; OS11).	G	*Medium confidence*: Increase of HP (T06; OS11).	G	*Low confidence:* inconsistent signal of change in CDD (T06; SW08; OS11).	G
Australia/New Zealand	Whole Australia and New Zealand	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease in all regions (CSIRO and Bureau of Meteorology, 2007; Kharin et al., 2007; Mullan et al., 2008; OS11).	G **R**	*High confidence*: WN *very likely* to increase everywhere (T06; Kharin et al., 2007; Alexander and Arblaster, 2009; OS11) and CN *very likely* to decrease (OS11). *Medium confidence*: WN increase everywhere. Largest increases in WN in N compared with S and most consistent changes in inland regions (Alexander and Arblaster, 2009).	G	*High confidence: Likely* increase of HWDmax on the annual time scale (T06; OS11) and increase of HWD everywhere (Alexander and Arblaster, 2009). *Medium confidence:* Strongest increases in HWD in NW & most consistent increases inland (Alexander and Arblaster, 2009).	G	*Low confidence*: Lack of agreement regarding sign of change (T06; OS11). *Low confidence:* 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).	G	*Lowto medium confidence:* Models agree on increase in CDD in southern Australia, but inconsistent signal over most of South Australia in SM; inconsistent signal in CDD and SM in Northern Australia (T06; SW08; OS11). Strongest CDD increases in western half of Australia (Alexander and Arblaster, 2009).	G
	Northern Australia	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease (CSIRO and Bureau of Meteorology, 2007; OS11).	G	*High confidence*: WN *very likely* to increase (T06; Alexander and Arblaster, 2009; OS11) and CN *very likely* to decrease (OS11). *Medium confidence:* Changes larger than in Southern Australia (Alexander and Arblaster, 2009).	G	*High confidence: Likely* increases of HWDmax on the annual time scale (T06; OS11) and increases in HWD everywhere (Alexander and Arblaster, 2009). *Medium confidence:* Strongest increases in NW & most consistent increases inland (Alexander and Arblaster, 2009).	G	*Low confidence* (see whole region)	G	*Low confidence:* Inconsistent signal in CDD and SM (T06; SW08; OS11).	G
	Southern Australia and New Zealand	*High confidence*: HD *very likely* to increase & CD *very likely* to decrease (CSIRO and Bureau of Meteorology, 2007; OS11). *Low to medium confidence:* Strongest New Zealand increases in HD in North Island and largest decreases in frost days in South Island (Mullan et al., 2008).	G **R**	*High confidence*: WN *very likely* to increase (T06 , (T06; Alexander and Arblaster, 2009; OS11) and CN *very likely* to decrease (OS11). *Medium confidence:* Changes smaller than in Northern Australia (Alexander and Arblaster, 2009).	G	*High confidence: Likely* increases of HWDmax on the annual time scale (T06; OS11) and increase in HWD everywhere (Alexander and Arblaster, 2009). *Medium confidence:* Most consistent increases inland (Alexander and Arblaster, 2009).	G	*Low confidence* (see whole region) *Low to medium confidence:* In New Zealand, increase in HP events at most locations (Mullan et al., 2008; Carey-Smith et al., 2010).	G **R**	*Medium confidence:* Models agree on increase in CDD in southern Australia including SW (T06; Alexander and Arblaster, 2009; OS11), but inconsistent signal in SM over most of the region, slight decrease in SW (T06; SW08; OS11).	G

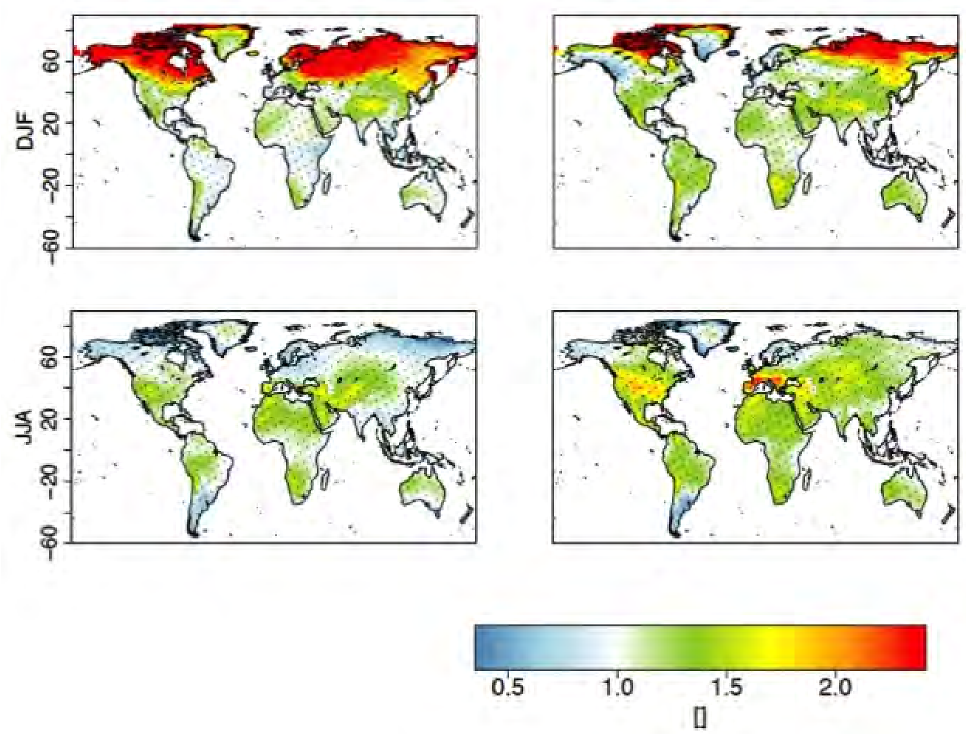


Figure 3.1: Scaling between globally-averaged annual mean projected change in Tmax and spatial changes in seasonal (DJF, top; JJA, bottom) changes in 10%ile (left) or 90%ile (right) of Tmax, CMIP3 projections, 2080-2100 time frame minus 1980-2000 time frame (A2 vs 20C3M). The 10%ile and 90%ile values are computed from pooling all data for the respective months in the two 20-year periods. [adapted from Orlowsky and Seneviratne, 2011]

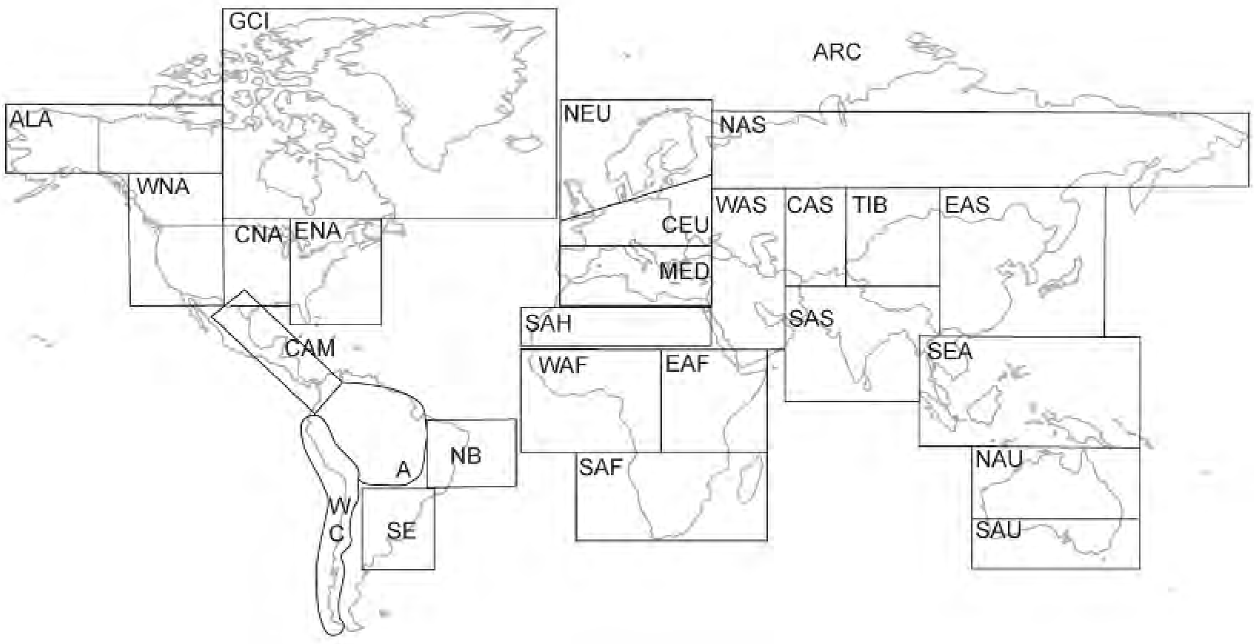


Figure 3.2: Definitions of regions used in Tables 3.2 and 3.3.

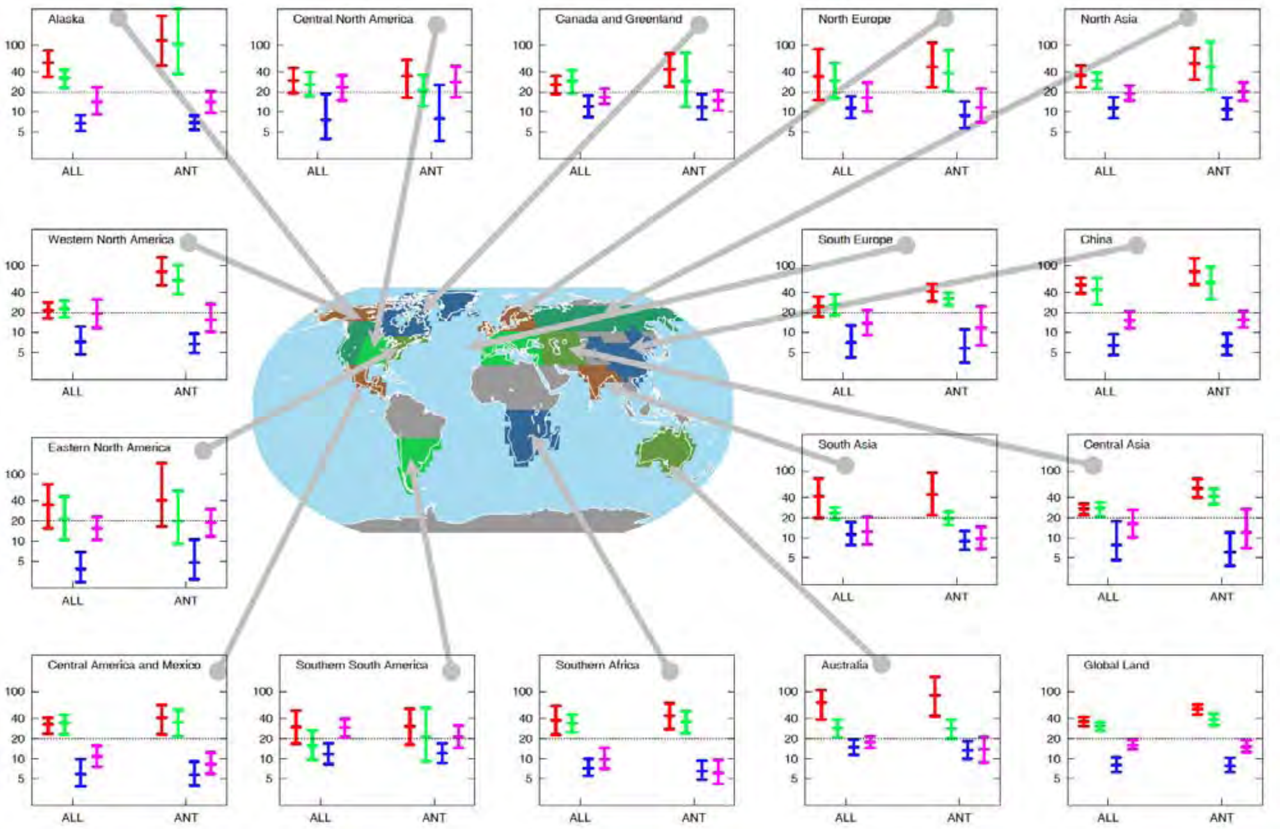


Figure 3.3: Estimated waiting time (years) and their 5% and 95% uncertainty limits for 1960s 20-yr return values of annual extreme daily temperatures in the 1990s climate (see text for more details). From Zwiers et al., (2011). Red, green, blue, pink error bars are for annual minimum daily minimum temperature (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.

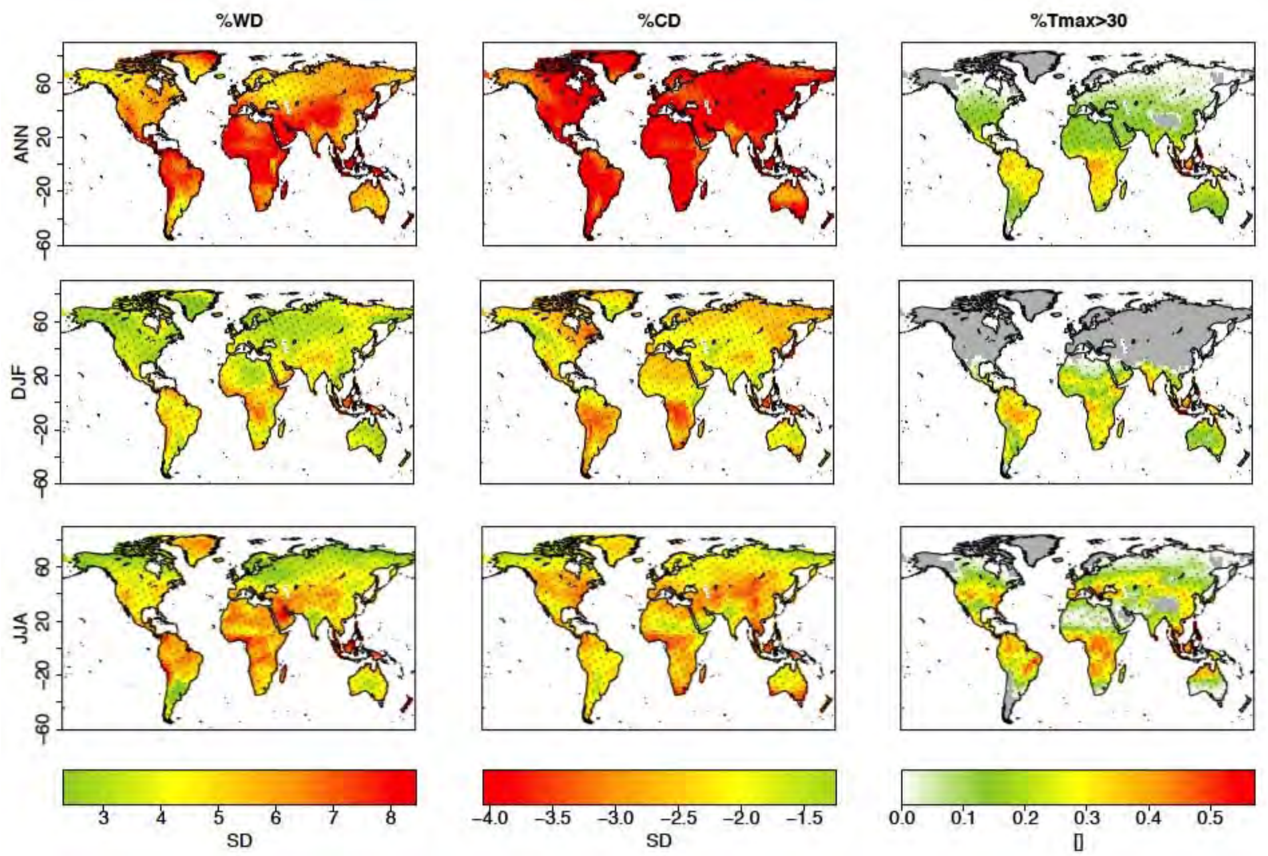


Figure 3.4: Projected annual and seasonal changes of three indices for Tmax: Fraction of warm days, fraction of cold days, and fraction of days with Tmax > 30°C; CMIP3 projections, 2080-2100 time frame minus 1980-2000 time frame (projections for A2 scenario, relative to late 20th century (20C3M) simulations), annual (top), DJF (middle) and JJA (bottom). Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].

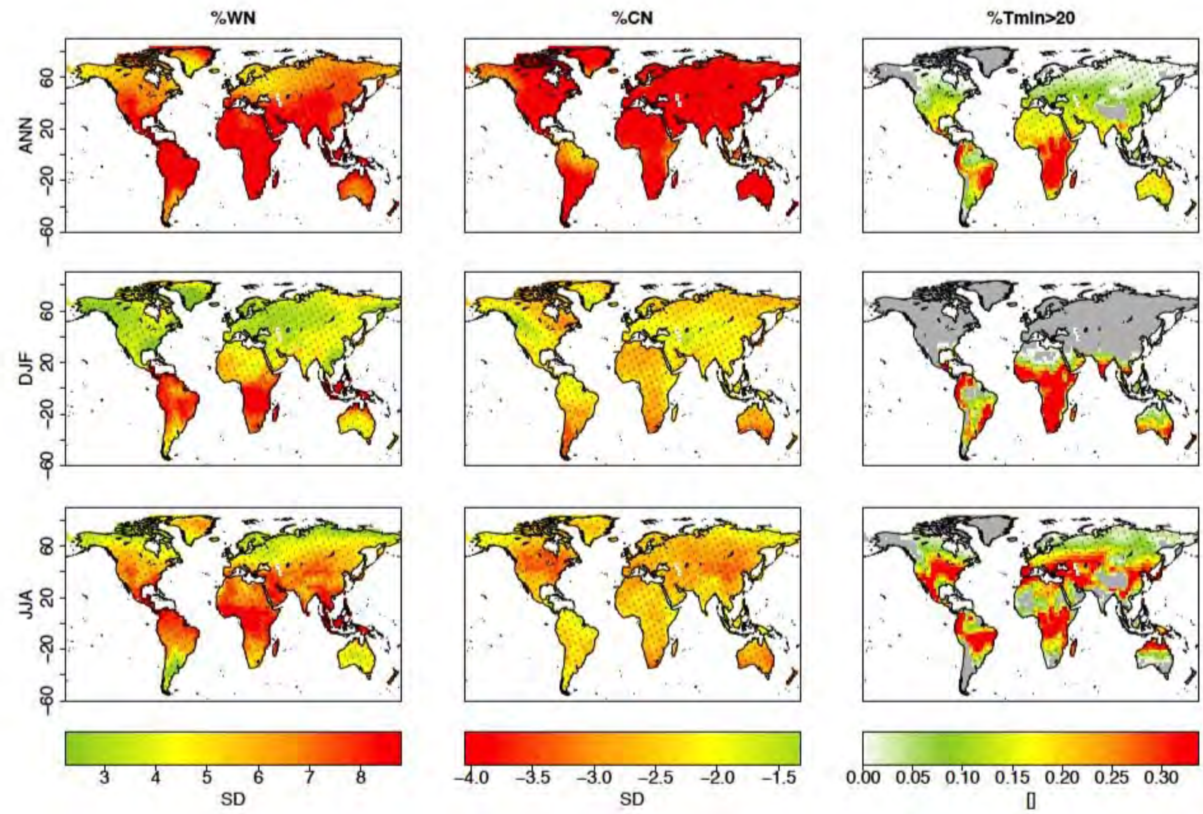


Figure 3.5: Projected annual and seasonal changes of three indices for Tmin: Fraction of warm nights, fraction of cold nights, and fraction of days with Tmin > 20°C; CMIP3 simulations, 2080-2100 time frame minus 1980-2000 time frame (projections for A2 scenario, relative to late 20th century (20C3M) simulations), annual (top), DJF (middle) and JJA (bottom). Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].

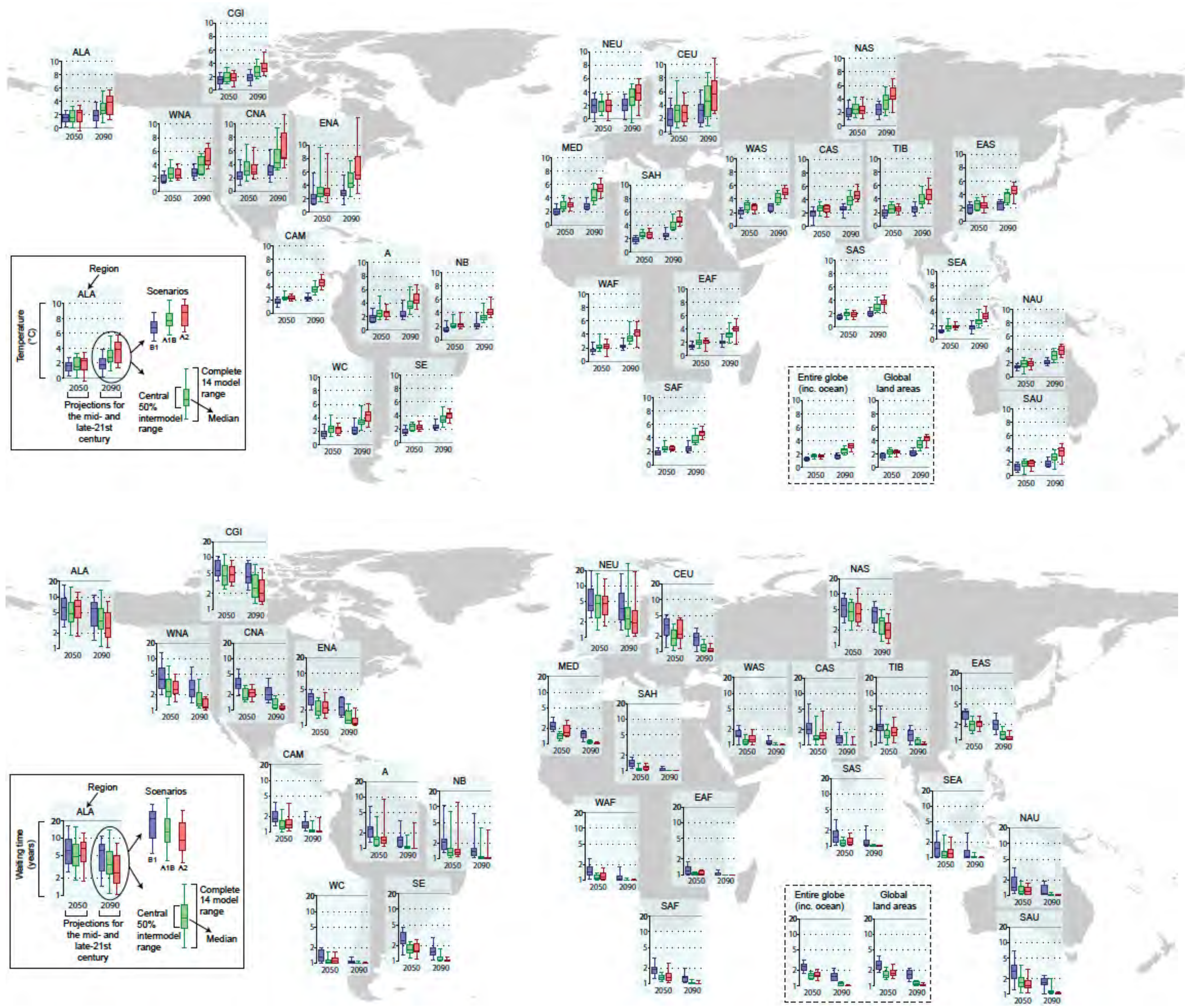


Figure 3.6: (a, top) Projected changes from the late-twentieth-century 20-year return values of annual maximum of the daily maximum temperature in the mid-21st century (left) and in late-21st century (right) by 14 GCMs that contributed to the CMIP3, under three different SRES emission scenarios B1 (blue), A1B (green) and A2 (red); units in °C. Adapted from the analysis in Kharin et al. (2007). The vertical extent of the whiskers shows the range of projected changes from 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). Model projections suggest that the the 20-year extreme annual daily maximum temperature will increase by about 2°C by mid-21st century and by about 4°C by late-21st century, depending on the region.
(b, bottom) Projected waiting times for late-twentieth-century 20-year return values of annual maximum of the daily maximum temperature in the mid-21st century (left) and in late-21st century (right) by 14 GCMs that contributed to the CMIP3, under three different SRES emission scenarios B1, A1B and A2 Adapted from the analysis in Kharin et al. (2007). The vertical extent of the whiskers shows the range of projected changes from 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). Model projections suggest that the waiting time for a late 20th century 20-year extreme annual daily maximum temperature will be reduced to about 2-20 years by mid-21st century and by about 1-5 years by late-21st century, depending on the region. Two global domains for which projections are shown are: the entire globe including the oceans, and the global land areas.

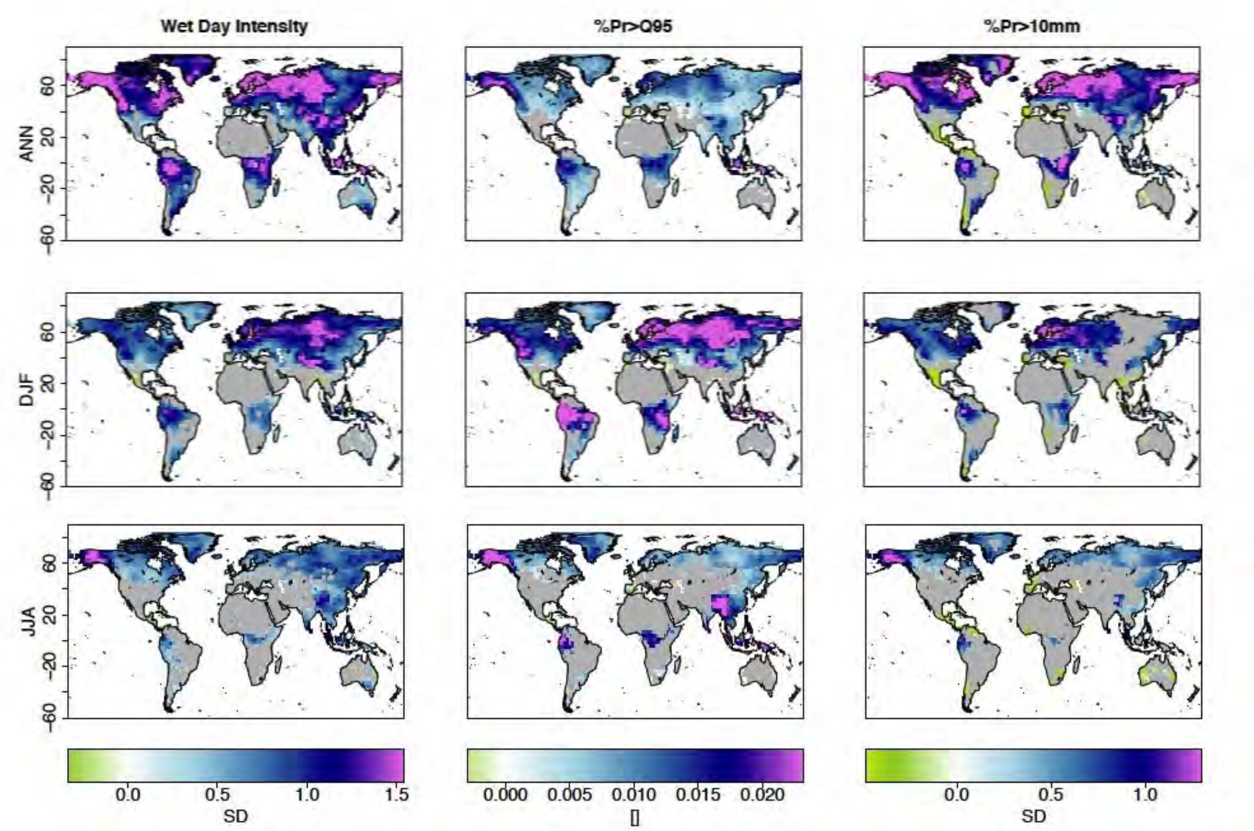
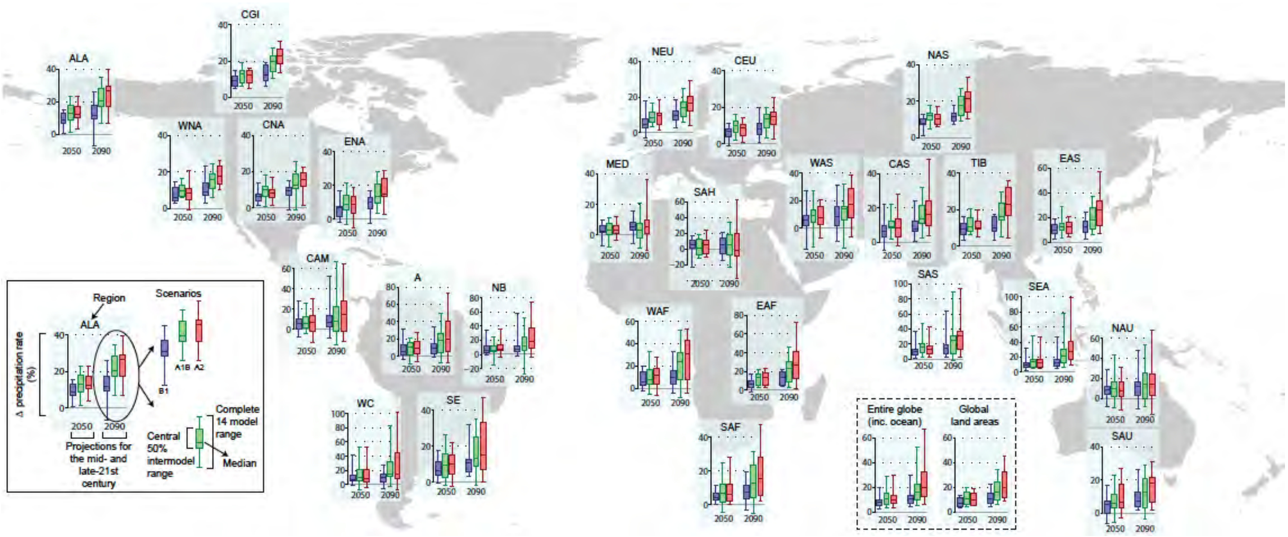


Figure 3.7: Projected annual and seasonal changes of three precipitation indices: Wet day intensity, fraction of days with precipitation above the 95%-quantile of daily wet day precipitation and fraction of days with pr > 10 mm; CMIP3 simulations, 2080-2100 time frame minus 1980-2000 time frame (projections for A2 scenario, relative to late 20th century (20C3M) simulations), annual (top), DJF (middle) and JJA (bottom). Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].



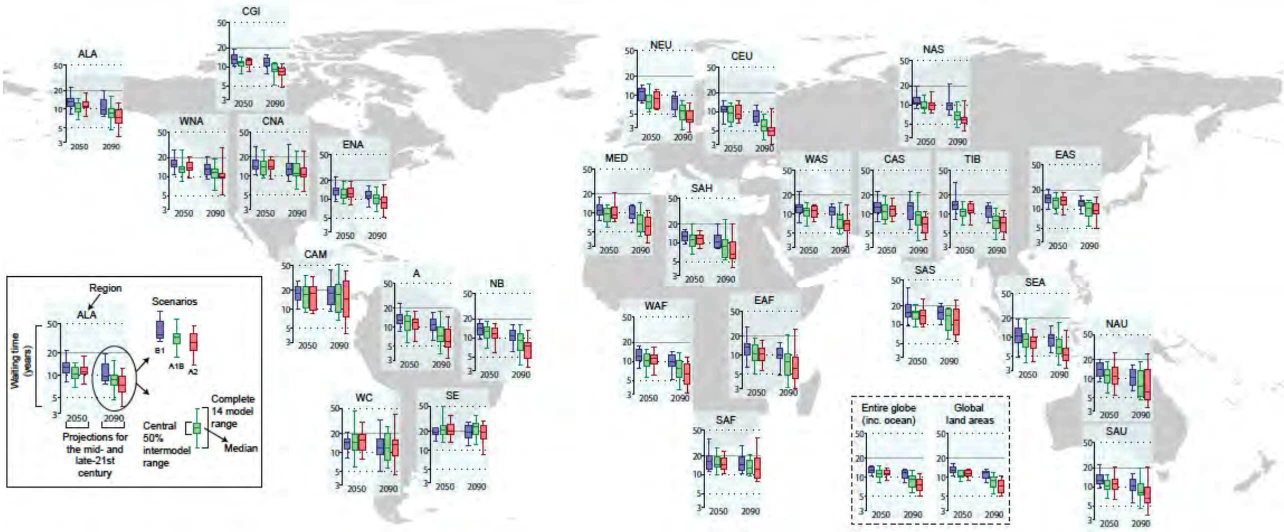


Figure 3.8: (a, top) Projected changes from the late-twentieth-century 20-year return values of annual maximum 24-hour precipitation rates (%) in the mid-21st century (left) and in late-21st century (right) by 14 GCMs that contributed to the CMIP3, under three different SRES emission scenarios B1 (blue), A1B (green) and A2 (red); (adapted from Kharin et al., 2007). The vertical extent of the whiskers shows the range of projected changes from 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 projected change in extreme precipitation is large, the median model projection is that the extreme 24-hour precipitation rate will increase by about 5-10% by mid-21st century and by about 10-20% by late-21st century, depending on the region and the emsissions scenario.
(b, bottom) 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 CMIP3, under three different emission scenarios SRES B1 (blue), A1B (green) and A2 (red) (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 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. Two global domains for which projections are shown are: the entire globe including the oceans, and the global land areas.

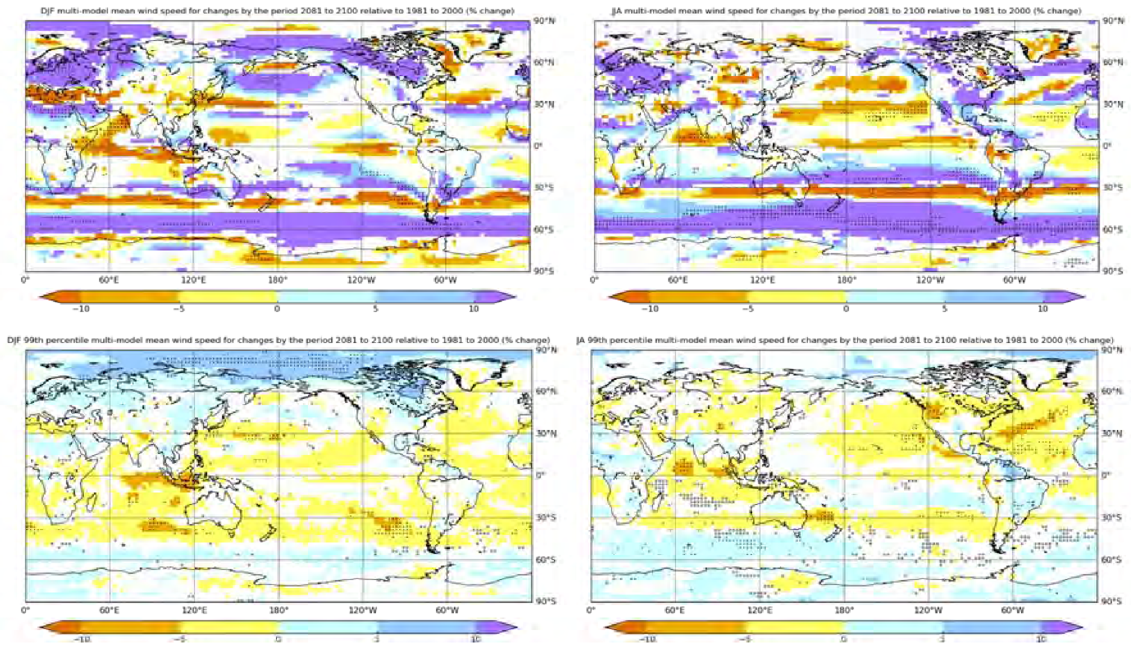


Figure 3.9: The average of the projected multi-model 10 m mean wind speeds (top) and 99th percentile daily wind speeds (bottom) for the period 2080 to 2099 relative to 1980 to 1999 (% change) for December to February (left) and June to August (right) plotted only where more than 66% of the models agree 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., (2011).

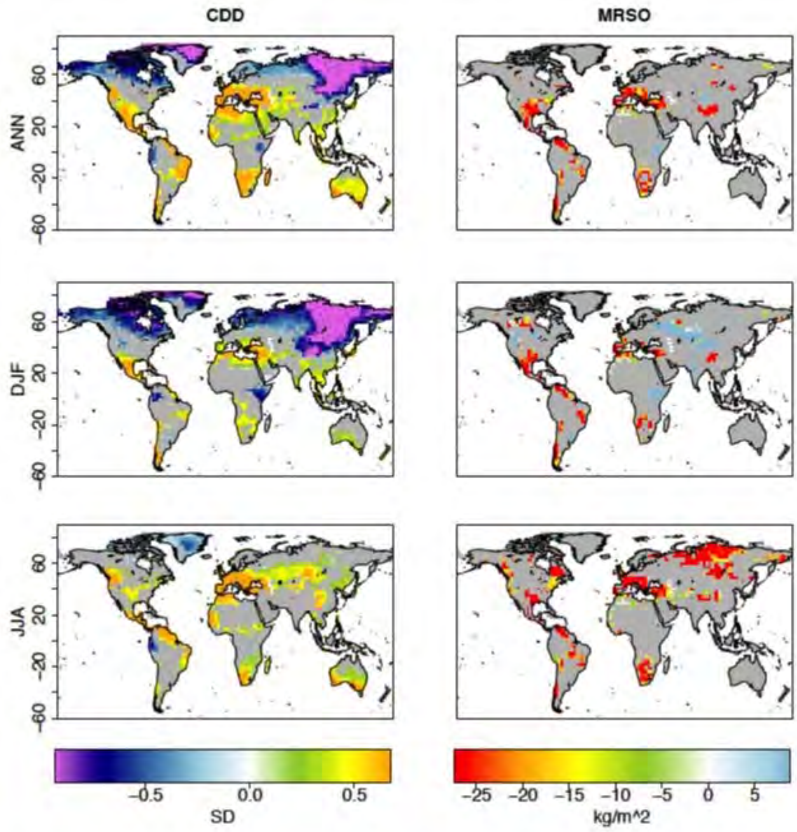
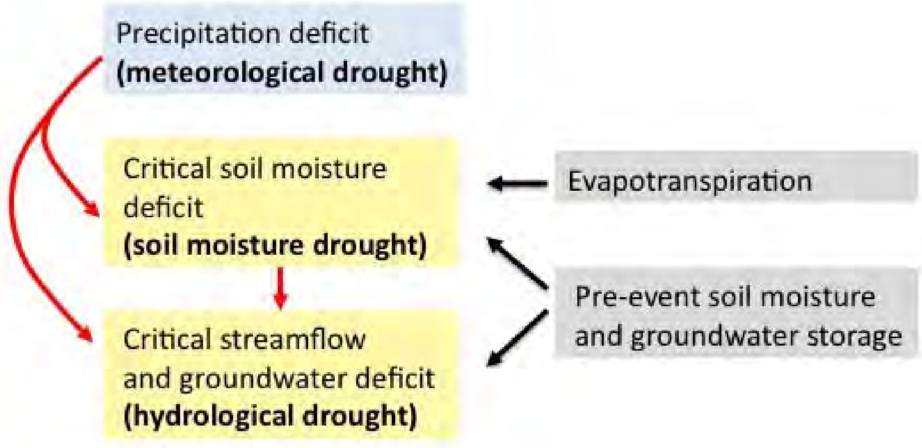
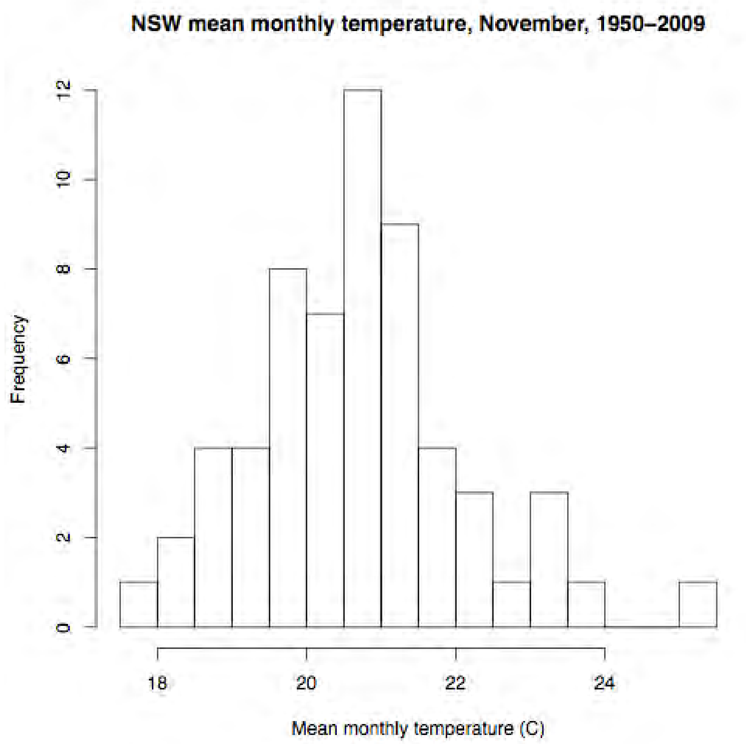


Figure 3.10: Projected annual and seasonal changes of two dryness indices: Consecutive dry days (CDD, days with pr < 1 mm) and average soil moisture (mrso); CMIP3 projections, 2080-2100 time frame minus 1980-2000 time frame (A2 relative to 20C3M simulations), annual (top), DJF (middle) and JJA (bottom). Shading is only applied for areas where at least 66% of the models agree in the sign of the change; stippling is applied for regions where at least 90% of all models agree in the sign of the change [from Orlowsky and Seneviratne, 2011, after Tebaldi et al., 2006].



Box 3.2, Figure 1: Processes and drivers relevant for meteorological, soil moisture, and hydrological droughts.



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

Extreme impacts can result from extreme climate events, but can also occur without extreme events. The chapter examines two distinct types of “extremes”: weather and climate extreme events; and secondly, extreme impacts on human and ecological systems. Although extreme impacts often follow an extreme event, either extreme can occur without the other. Serious negative impacts on humans and ecosystems can occur even without weather and climate extremes. This is because the impacts of these extremes are a function of exposure, vulnerability and the type and

magnitude of the climate event. Gradual climate change can have major effects on vulnerability and exposure greatly increasing the impacts of climate events. Similarly, changes in human systems and ecosystems can also have major effects on vulnerability and exposure, and therefore on impacts. To a lesser extent weather and climate events can also have positive impacts for some ecosystems and economic sectors.

There is high confidence that absolute losses from weather-related disasters are increasing (see Sections 4.2.5; 4.6.3.1). There is high agreement, but medium evidence that anthropogenic climate change has so far not lead to increasing losses. This is particularly the case for large scale extreme events such as windstorms (including cyclones) and river floods (see Section 4.2.5). This conclusion is contingent on data availability (most data are available for developed countries), type of hazards studied (many studies focus on cyclones, where there is low confidence in an anthropogenically induced change in the hazard (see Section 3.3.3)), and finally on the methods used to normalize loss data over time.

Exposure of people and economic assets to climatic extremes is almost certainly increasing, and is very likely the major cause of the long-term changes in economic disaster losses [high confidence]. There is some evidence that human exposure is increasing more quickly in high hazard rapidly developing areas, apart from areas prone to severe drought.

Trends in vulnerability vary greatly by location and demography with some areas and groups showing increases and others decreases. But there is no agreement on global trends – and generalizations may be inappropriate due to vulnerability's immense variability.

Impacts of extreme events are almost certain to increase with climate change. However, few studies have addressed non-climatic factors, such as exposure and vulnerability changes, thus the confidence in these projections is low. Projected future weather related loss studies mostly focus on tropical cyclones in the US and floods in Europe and the US, although some studies have addressed flash floods and hail damage. For the studies that do consider socioeconomic as well as climate change, there is *medium agreement*, but *limited evidence* that the expected changes in exposure are at least as large as the effects of climate change. Indirect and intangible losses are rarely addressed (see section 4.6.3).

Adaptation costs and disaster losses for the projected increasing climate and weather extremes will increase the costs of development. There is medium agreement and evidence that this increase could almost halt economic development in some areas

Climatic extremes are observed to have widespread negative effects on biodiversity and ecosystems, including physiology, development, phenology and carbon balance. Ecosystem services can be seriously impaired by extreme weather and climate events. Ecosystem susceptibility to negative impacts is increased when already stressed by human caused ecosystem fragmentation, deforestation, urbanization, road and infrastructure corridors, environmental contamination and residual damage from earlier events.

Extreme events are more likely to have major impacts on some sectors than others due to their close links with climate, in particular agriculture and food security. Tourism is also especially sensitive to extremes. To reduce the vulnerability of many economic sectors, private commercial interests need to be involved. Settlements combine and concentrate the exposure of many sectors including infrastructure, transport and most components of manufacturing and trade. Because of the connected nature of these sectors vulnerabilities in one are likely to impact negatively on other sectors.

Regions are impacted differently by extreme events. However, in most regions, the severity of the impacts of extremes such as heat waves and wildfires, droughts and floods (fluvial and coastal), are projected to increase. This is largely due to increases in exposure and variations in vulnerability and adaptive capacity. Some regions and sub-regions, including some emerging major economies, may be impacted severely by climate extremes to the extent that the viability of government finances is put at risk.

There is robust evidence and high agreement that deforestation induces decreases in precipitation and increases in local temperatures in tropical areas. It is very likely that a dryer and warmer local climate will exacerbate forest fires. When combined with increasing exposure there may be severe forest fire impacts in areas without such experience.

Most estimates of disaster impacts are based on direct losses, recorded largely as monetized direct damages to infrastructure, productive capital stock and buildings, only, and as a result seriously underestimate loss (see Section 4.6.1.1). For example, this is the case with the widely used database EM-DAT. This approach excludes indirect losses which are primarily the economic flows that constitute livelihoods and economies, and intangible losses which include ecosystem services, human lives, quality of life and cultural impacts.

Global observed climate related disaster impacts over the last few decades reflect mainly monetized direct damages to assets, and are unequally distributed (see section 4.6.3.1). Annual accumulated estimates have ranged from a few billion to about 250 billion USD (in 2009 values) for 2005 (the year of Hurricane Katrina) (see section 4.2.5). Over the period of 2000-2008, the Americas suffered the most direct economic damage in absolute terms accounting for 55% of the total damages, followed by Asia (28%) and Europe (16%), while Africa accounted for only 0.6%. When expressed as a proportion of GDP, estimated losses of natural disasters in developing regions (particularly in East and South Asia and the Pacific, Latin America and the Caribbean) are higher than those in developed regions [*high confidence*]. Over the 25 year period of 1980 to 2004, direct losses have amounted to 0.15% of GDP in high income as compared to 0.5% for low income countries (see section 4.6.XX). In individual events, disasters can cause massive losses, such as in small economies and small island states, where in St. Lucia in 1998 the asset losses measured as a percentage of GDP exceeded 350% (*high confidence*; see 4.6 XX). In terms of observed and modelled indirect losses, there is *robust evidence and* medium agreement that extreme events can cause important adverse macroeconomic and developmental effects, such as 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 (see section 4.6.1.2).

Definitions: For practical reasons, both the concept of "extremes" and "rarity" are not amenable to precise definition. Varying spatial and temporal scales, and the very large 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.

There is medium uncertainty in assessments of impacts of extreme weather events, and high uncertainty when impacts are projected into the future. Beside sources of uncertainty identified in Chapter 3, there are also major uncertainties in future social values and technologies.

4.1. Introduction

Chapter 3 establishes the current status and possible changes in the frequency and intensity of weather and climatic extremes. 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. The emphasis is on negative impacts, but climate events can and often do have positive impacts for both some people and ecosystems.

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. 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.

The Chapter examines concepts and definitions, in particular the concept of “extreme”. Examination of trends in disaster impacts highlights the difficulties in the attribution of trends in climate related disasters to climate change. Issues and trends in exposure and vulnerability and their relationship with extreme events are discussed. The Chapters then examines system- and sector-based aspects of vulnerability, exposure and impacts, both observed and projected. The same issues are examined by the IPCC regions, before the Chapter concludes with a section on the costs of climate related disasters and adaptation. Most material on the costs of afaptation is in subsequent chapters.

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; ... the vast majority of disasters registered annually in particular disaster data bases are not associated with extreme physical events as defined probabilistically…but many have important and even extreme impacts for local and regional societies…”

The definition is expanded further in Chapter 3, Box 3-1. This makes the point that “Weather and climate events” are atmospheric phenomena, quite separate from human exposure and vulnerabilities. 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 [human or ecosystem] thresholds”. Extreme impacts may result from the accumulated effect of several non-extreme events “as is the case for compound events or multiple clustered events” (see Section 3.1.4 and Box 3.4). Extreme events (defined in Section 3.1.1.1) on the other hand, do not “necessarily lead to major impacts and disasters”, unless the impacted system is vulnerable to that event.

Note that in this Chapter the expression “climate event” is used to refer to weather and climate events.

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” (see 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) 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 often 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, for example exposure and vulnerability. 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 unusual 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, e.g. 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 40°C and a relative extreme such as the 95% percentile. Mathematically speaking, extremely high mean annual temperature also belongs to the realm of climate extremes. Nine out of ten years from the decade of 2000s belong to a set of ten globally warmest years in the history of instrumental record (cf., IPCC, 2007, updated). Chapters 1 and 3 examine these dimensions.

Not all occurrences of extreme values of climatic variables cause damage. Some of them may bring benefits, e.g. floods can bring human benefits, such as food security, as with the Nile floods in history (Shaw, 2003), and annual monsoon flooding in many parts of the world. Floods may also bring ecological benefits, for example wildfires in fire dependent ecosystems (Beckage, Platt and Panko, 2005), and the flooding of Lake Eyre in Australia making the adjacent desert bloom (Kotwicki, 1986).

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. Today, considerable effort around the world is devoted to preventing, reducing and managing the impacts of extreme events (Yohe and Tol, 2002; Bartlett, 2008). 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 the psychological aspects of extremes, including the roles of religion and spirituality (Reale, 2010), in managing impacts (Hess, Malilay and Parkinson. 2008; De Cordier, 2009; Fountain, Kindon and Murray, 2004). While most attention goes on the negative impacts, extremes may also generate economic benefits (eg Handmer and Hillman, 2004), 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 (Anderson, 1990).

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 (Victorian Royal Bushfire Comission, 2010; Bernard et al., 2006)), thereby increasing the overall impact of the event sometimes making these impacts global (Schneider et al., 2010; Birkland, 1997; Kurtz, 2008). 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 1948), or even possibly contributed to or triggered the collapse of societies (e.g. 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. Box 4.2 discusses this issue.

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 various techniques such as raising dwellings above flood level 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 *unlikely* as humanity spreads assets and activities into almost every location (Pedduzi et al., 2009; Hess, Malilay and Parkinson. 2008; Yohe and Tol, 2002).

Poorer rural areas where livelihoods are heavily or solely dependent on farming or fishing often 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 (Dodman and Satterwaite, 2009). The food security of farmers, partly or wholly dependent on substinence agriculture, is tied directly to an ability to reduce the impacts of extreme climate events. 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 – in contrast to the worldwide trend in commercial agriculture to monocultures which increase the impact of droughts (Aggarwal and Singh, 2010). The occurrence or high chance of 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 (Satterthwaite et al., 2007).

4.2.1.1.1. The role of wealth

Wealthier societies and areas expend much effort to reduce the impact of extremes and to adjust to regular weather events (Anbarci et al., 2005; Kahn, 2005; Toya and Skidmore, 2007). They do this through design standards for all infrastructure, buildings etc. Wealthy countries have the capacity to build roads, bridges, large dams and drainage systems (Cembrano, 2004) to withstand specified flood frequencies (Benedict and McMahon, 2002). Structures are designed for certain wind speeds (Baker, 2007), and in some cases to be resistant to earthquakes (Erdik, 2001). The result is a reasonably high level of protection against climate extremes. Certain sectors of any country are very susceptible to the impacts of extremes including; agriculture (Schmidhuber and Tubiello, 2007), transportation (Bureau of Transport Economics, 2001) and weather dependent tourism (Amelung, Nicholls and Viner 2007). 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 (Douglas, 2009; MacDonald and Calow, 2009).

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 event from a wealthy area to a poorer one. More formal approaches to risk transfer have evolved (Benson and Clay, 2004) (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 greenhouse gas emissions.

People in poorer countries are generally far less insulated from climate extremes (Peduzzi et al., 2009a) as well as geological extremes (Anbarci et al., 2005). Many people are preoccupied with day to day existence in a context where even frequent non-extreme events result in severe impacts (see Chapter 1). 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 (Mirza, 2003; Benson and Clay, 2004; Kahn, 2005; Toya and Skidmore, 2007; Ibarraran et al., 2009; Lis and Nickel, 2010).:

- Dominica, hurricanes David and Allen, 1979: 20% of GDP (Ibarraran et al., 2009; Benson and Clay, 2000)
- Turkey, Kocaeli and Duzce Earthquakes, 1999: 7% of GDP (Erdik, 2001)
- USA, Hurricane Andrew, 1992: <1% of GDP (Cashell, 2005)

The current consensus is that the impacts of extreme events have a relatively linear relationship to a country's wealth – with small island countries being especially likely to suffer extreme impacts due primarily to the exposure of most of their assets and people to a single climatic event (FitzGerald, 2008; Hess, Malilay and Parkinson, 2008). This has been challenged by Kellenberg and Mobarak (2008), who suggest that the relationship instead falls on a normal distribution. This means that middle, richer than the poorest income countries are likely to suffer the worst damages.

Most of the human impacts of natural disasters are in the developing world (Kahn, 2005; Toya and Skidmore, 2007; Peduzzi, 2009), as shown by the following figures illustrating the dramatic difference between rich and poor countries (IFRC, 2009 – from the IFRC database of 3950 disasters from 1999 to 2008):

- HDC (highly developed countries): 66 deaths per disaster

- MDC (countries with a medium level of development): 353 deaths per disaster
- LDC (least developed countries): 705 deaths per disaster.

Climate extremes, exposure and vulnerability are characterised by uncertainty and continuous change. 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 (Campbell-Lendrum and Corvalán, 2007). In the short term the main implications are for the groups that traditionally manage disasters and emergencies (Medonca and Wallace, 2004). They are and likely will be seen as responsible for managing these evolving risks and the increased complexity in impacts they bring.

Poverty and exposure are important factors in generating extreme impacts from climate events. However, a comparison between the 2007 cyclone Sidr in Bangladesh and cyclone Nagis in Myanmar in 2008, demonstrates dramatically the importance of other factors in vulnerability to extreme events. Bangladesh experienced relatively few casualties during Sidr (Paul, 2009), in contrast with Cyclone Nargis in Myanmar, where the death toll exceeded 138,000 fatalities making it the eighth deadliest cyclone recorded worldwide (Fritz *et al.*, 2009). This comparison is examined in detail in Chapter 9.

4.2.1.2. Role in Natural Systems

Many ecosystems are dependent on extremes for reproduction (e.g. fire, floods, wind dispersal), disease control (cold, dry periods), and in many cases general ecosystem health (fires, windstorm 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 (Rogers, 2010); fires that are essential 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 atmospheric systems are driving changes in many climatic variables and the corresponding impacts (see Chapter 3). 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 focussing on the impacts from extreme precipitation events and flooding. Box 4.1 illustrates some of these issues for wildfires.

Changes in socio-economic status are a key component of exposure; in particular population growth is a major driver behind changing exposure and vulnerability (Barredo, 2009; Downton, Miller and Pielke, 2005). In many regions, people have been encroaching into 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 a risk 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 (Grothmann and Patt, 2005) (e.g. 2005 hurricane Katrina in New Orleans).

Economic development and land-use change can also lead to changes in all natural systems. Land-cover changes induce changes in rainfall-runoff patterns, which can impact on flood intensity and frequency. Deforestation, urbanization, reduction of wetlands and river regulation (channel straightening, shortening, embankments) change the percentage of precipitation becoming runoff by reducing the available water storage capacity (Few, 2003; Douglas *et al*, 2008). The proportion of impervious areas (e.g. roofs, yards, roads, pavements, parking lots, etc.) and the value of the runoff coefficient are increased. 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 potentially endangered by landslides and debris flows, triggered by intense rains. These changes have resulted in less extreme rain leading to serious impacts (Crozier, 2010).

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 (Dregne, 1986). 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 in Central Asia. Due to excessive and non-sustainable water withdrawals from the tributaries (Syr Darya and Amu Darya), their inflow into the Aral Sea has shrunk in volume by some 75% (Micklin, 2007).

The climate change impact on sectors, such as water and food, depend 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 and pressure (Kundzewicz, 2003).

Possible interactions of several hazards may also be an increasing threat, where cascading and conjoint effects result in increasing threats to society (Cruz, 2005). A conjoint hazard may be defined as several climatic hazards, generally independent of each other, that 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 the case of cascading hazards, one hazard may influence other hazards (as heat wave and drought may create the condition for wildfire) or exacerbate their effects. The influence is also likely to be scale-dependent (Buzna et al., 2006). For example, temperature rise leads to permafrost thaw, reduced slope stability and damage to buildings. Another example is that intense precipitation leads to flash flood, land slides and infrastructure damage – collapse of bridges, roads, and buildings, and interruption of power and water supplies. In the Philipines two tropical storms developed into two typhoons hitting the south of Luzon Island in 2004. This caused a significant flood disaster as well as landslides on the island leading to 900 fatalities (Pulhin et al., 2010). 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 4-1 HERE _____

Box 4-1. Evolution of Climate, Exposure, and Vulnerability – The Melbourne Fires, 7 February 2009

The fires in the Australian state of Victoria on February 7, 2009, demonstrate the evolution of risk through the relationships between the climate and weather related phenomena of a decade long drought, record extreme heat and record low humidity of 5% (Karoly, 2009; Trewin and Vermont, 2010) interacting with rapidly increasing exposure. Together the climate phenomena created the conditions for major uncontrollable wildfires (Royal Commission, 2009). The long drought, record heat and a 35 day period with no rain immediately before the fires, turned areas normally seen as low to medium wildfire risk into very dry high risk locations. A rapidly expanding urban-bush interface and valuable infrastructure (Berry, 2003; Burnley and Murphy, 2004; Costello, 2007, 2009) provided the values exposed and the potential for extreme impacts which was realised with the loss of 173 lives and considerable tangible and intangible damage. There was a mixture of natural and human sources of ignition, showing that human agency can trigger such fires and extreme impacts.

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 because of their age or other impairments struggled to cope with the extreme heat and were reliant on others to respond safely (Handmer *et al*., 2010). However, capacity to recover in a general sense is high for humans and human activities through insurance, government support, private donations, and NGOs and poor for the affected ecosystem (Millenium Ecosystem Assesment, 2005)

With climate change, such hot dry conditions are *very likely* to become more frequent.[1] (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.

[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).]

_____ END BOX 4-1 HERE _____

4.2.2.1. Extreme Drought and Forest Fires: A Positive Feedback and Threat to Tropical Forests, Biodiversity, and Climate in Asia and Latin America

Forest Fires and Wildfires (FFW), including peat fires, are the only hazards which are both exacerbating and are exacerbated by climate change. After volcanic eruptions, FFW release the second largest quantities of GHG (Randerson *et al*., 2002a–d; Page *et al*., 2002; Cochrane, 2003; Nepstad *et al*., 2004; Jones and Cox, 2005; Kasischke *et al*., 2005; Randerson *et al*., 2005; Van der Werf, 2008). The frequency and extent of FFW are *likely* to increase under a warmer climate (IPCC AR4, 2007). Old-growth forests have steadily accumulated vast quantities of carbon for centuries. They will lose much of this carbon to the atmosphere if they are disturbed (Luyssaert *et al*., 2008).

To this positive feedback (red loop in Figure 4-1) is added to the deforestation process. There is *robust evidence* and a *high degree of agreement* that deforestation decreases precipitation and increases local temperatures in tropical areas (Nobre, 1991; Olivry *et al*. 1993; Zheng *et al*. 1997; Mahé and Olivry, 1999; Costa and Foley, 2000; Zhang *et al*., 2001; Kanae *et al*., 2001; Delire *et al*., 2001; Durieux et al, 2003; Sen *et al*., 2004 ; Betts *et al*. 2004 ; Sampaio *et al*., 2007 ; Ramos da Silva *et al*., 2008). A dryer and warmer local climate is *very likely* to exacerbate forest fires (Hofmann *et al*., 2003; Van der Werf *et al*., 2008; Nepstad, 2008; Aragão *et al*., 2008) and induce a second positive feedback (see orange loop in Figure 4-1).

[INSERT FIGURE 4-1 HERE:
Figure 4-1: Simplified Diagram of the Positive Feedbacks between Drought, Forest Fires, and Climate Change.]

While past studies, during the period from 1982 to 1999, suggest that more biomass would be produced under warmer temperatures and higher concentrations of CO_2 (Nemani *et al*., 2003), measurements over the period 2000-2009 (the warmest decade ever recorded), revealed that the biomass decreased by 0.55 Mt (Zhao and Running, 2010). This may be attributed to large-scale regional droughts and a general drying trend over the Southern Hemisphere (SH).

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). A reduced forested area leads to a decrease in photosynthesis and thus a decrease in carbon sink capacities (Zhao and Running, 2010; FAO, 2010). These two processes decrease carbon sink capabilities and lead to a third positive feedback (gray loop in Figure 4-1) accelerating the processes in the two other loops. Photosynthesis needs not only CO_2 but also H_2O, and the latter can be the limiting factor. Studies of Amazonia confirm the link between water deficit and decrease in biomass production (Phillips *et al.*, 2009).

More research on these processes is required since one cannot exclude teleconnection mechanisms where heat, moisture, and/or wave energy are transferred to higher latitudes (Zhao *et al.*, 2001; Avissar and Werth, 2005; Hasler *et al.*, 2009).

4.2.2.1.1. Deforestation, fires, drought, and climate change in Asia

In AR4, it is already stated that "as a consequence of a 17% decline in spring precipitation and a rise in surface temperature by 1.5°C during the last 60 years, the frequency and aerial extent of the forest and steppe fires in Mongolia have significantly increased over a period of 50 years" (Erdnethuya, 2003 in AR4). The observations in the past 20 years show that the increasing intensity and spread of forest fires in North and South-East Asia were largely related to rises in temperature and declines in precipitation, in combination with increasing intensity of land use (IPCC AR4, Section 10.2.4.4).

In recent studies, Sumatra's fire emissions show a positive linear trend, approximately doubling between 2000 and 2006. Furthermore, Van der Werf et al. found that a "strong nonlinear relation between drought and fire emissions in southern Borneo highlights the sensitivity of the region to climate change" (2008, pg. 20351). They also indicated that "increased anthropogenic use of fire with drought may be an important positive feedback between climate and the carbon cycle during the 21st century" (Van der Werf et al., 2008, pg. 20353) In a dryer and warmer climate, emissions from this region have the potential to increase substantially (Van der Werf *et al.*, 2008) (see Figure 4-2).

[INSERT FIGURE 4-2 HERE:
Figure 4-2: Dry Season Length and Fire Detections for the Strong 2000 La Niña and 2002 and 2006 Moderate El Niño Years.]

In tropical Asia, although humans are igniting the fires, droughts act as triggers for fire occurrence and large fire events were found to occur when precipitations dropped below 609 mm (Field *et al.*, 2009). Drought episodes, forest fires, drainage of rice fields and oil palm plantations are drying the peatlands which are then more vulnerable to fires (Van der Werf *et al.*, 2008). Peatland fires are an important issue given the difficulties to extinguish them and their potential high impact on climate. In Indonesia and Papua New Guinea, the formation of peatland during the Holocene period led to the accumulation of potentially 70 Mt of carbon (Immerzi et al., 1992). This is comparable to the carbon stored in aboveground vegetation in the Amazon or to nine years of contemporary global fossil fuel emissions (Van der Werf *et al.*, 2008). Fires of peatlands in this region can therefore have significant impacts on climate.

The southern Borneo region is boxed and the dry season length and number of fire detections for this study region are shown in separate insets. The length of the dry season is given as number of months with < 100mm month^{-1} precipitation (blue-white) and the number of detected fires each year is shown in red–yellow.From Van der Werf *et al.*, (2008), reproduced with kind permission from the authors and courtesy of the National Academy of Science.

4.2.2.1.2. Deforestation, fires, drought, and climate change in Central and South America

"More frequent wildfires are *likely* (an increase in frequency of 60% for a temperature increase of 3°C) in much of South America" (AR4, 2007). Contributing to this are dryer conditions which are *likely* to increase. A tendency towards 'savannisation' of eastern Amazonia (Nobre *et al.*, 2005) and the tropical forests of central and South Mexico might occur (Peterson *et al.*, 2002; Arriaga and Gómez, 2004). In North-East Brazil the semi-arid vegetation could be replaced by the vegetation of arid regions (Nobre *et al*., 2005), as in most of central and Northern Mexico (Villers and Trejo, 2004).

Due to the interrelated nature of forest fires, deforestation, drought and climate change, isolating one of the processes is less relevant than looking at the new dynamic as a whole.

To illustrate the complexity of this dynamic, studies since AR4 confirm that drought is a factor in forest fires, which is subsequently a trigger for deforestation (Van der Werf et al., 2008; Nepstad, 2008; Aragão et al., 2008; Aragão and Shimabukuro, 2010). Yet deforestation feeds back into this loop; in the Amazon and Cerrado regions, deforestation was found to increase the duration of the dry season (Costa and Pires, 2009). In addition drought has caused Amazon forests to lose significant biomass. Forests that had a 100-millimeter increase in water deficit lost 5.3 Mg of aboveground biomass of carbon per hectare. Amazon forests therefore appear vulnerable to increasing moisture stress, with the potential of large carbon losses that will exert feedback on climate change (Phillips *et al*., 2009). Tropical deforestation contributes to climate change which substantially increases fire risk. “Both local and regional climate changes are likely to contribute to a positive feedback loop in which deforestation results in increased fire frequency and further reductions in tree cover” (Hoffmann *et al*., 2003).

A drastic deforestation scenario would result in a severe restructuring of land-atmosphere dynamics, partially explaining why most Atmospheric General Circulation Model (AGCMs) have predicted weakened water fluxes as a result of extensive deforestation (D'Almeida *et al*., 2007).

In eastern Amazonia the fires are initially lit in forest fragments on the edge of the main forest, but then penetrate deep into the forest interior (Cochrane and Laurance, 2002). Forest fragmentation, logging and human-ignited fires pose critical threats to Amazonian forests and may *trigger the transition of these seasonal forests into fire-dominated, low biomass forests* (Malhi *et al*., 2009).

One way to slow down these processes is to induce negative feedbacks into the loops described in Figure 4-1 such as combining protection and reforestation. An inventory of over 225,000 trees of tropical forest in Panama, (Chave *et al*., 2003) revealed that small trees were providing much of the biomass increase, however 60% of the biomass is contained in 1% of the larger diameter trees, while 97.6% of the smaller diameter trees contain less than 15% of the biomass. In this view, stopping (or slowing down) 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).

For tropical areas, there is robust evidence and high agreement that deforestation results in decreasd precipitation and increased local temperatures in tropical areas (Nobre, 1991; Olivry et al. 1993; Zheng et al. 1997; Mahe and Olivry, 1999; Costa and Foley, 2000; Zhang et al., 2001; Kanae et al., 20001; Delire et al., 2001; Durieux et al., 2003; Sen et al., 2004; Betts et al., 2004; Sampaio et al., 2007; Raamos da Silva et al., 2008).

In all regions a drier and wamer climate is very likely to exacerbate forest fire risk (hofmann et al., 2003; Van der Werf et al., 2008; Nepstad, 2008; Aragao et al., 2008).

4.2.3. How Do Climate Extremes Impact on Humans and Ecosystems?

4.2.3.1. Concepts and Human Impacts

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 now, a less extreme rain (compared with past records) may lead to very serious flooding impacts, due to increased economic exposure of people and activities. Reduced volumes of natural water storage on floodplains and wetlands; and increases in ground imperviousness and in runoff coefficients may cause higher river runoff from a given rainfall (Millenium Ecosystem Assesment, 2005).

Some changes to exposure and vulnerability can be considered as adaptive action. For example, migration away from high hazard areas (see Chapter 1 for a definition of hazard) reduces exposure and the chance of disaster and is also an adaptation to increasing risk from climate extremes (Revi, 2008; Adger et al., 2001; Dodman and Satterthwaite, 2009). Similar remarks could be made for changes to building regulations and livelihoods, among numerous other examples.

"Vulnerability" is defined here to mean susceptibility to harm and ability (or inability) to recover (EMA, 1998; also see Chapter 1.1.3.2). This section 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 fulfilment 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.) There is a significant literature on the definitional issues which include factors of scale and irreversibility (Quarantelli, 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).

Disasters result from impacts that require both exposure to the climate event and a susceptibility to harm by what is exposed. Impacts can include major destruction of assets and disruption to economic sectors, loss of human lives, mental health effects, loss and impacts on plants, animals and ecosystem services (see section 4.6).

Exposure can be conceptualised as human and ecosystem tangible and intangible assets and activities (including services) exposed to the weather or climate event and its energy (see chapter 2.2 for a detailed definition), without exposure there is no impact. 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. As human activity and settlements expand into an exposed area, more people will be subject to and affected by local climatic events. Population increase is predominantly in poor countries that are disproportionately affected by climatic hazards (Mendelsohn et al., 2006). In addition, many of the newly occupied areas were previously left vacant because they are hazardous, especially on the fringes of or in poorly-built infill in ever-growing urban areas (Satterthwaite et al., 2007). This is best seen in areas prone to flooding (Huq et al., 2007), landslides (Anderson et al., 2007) and industrial pollution, now occupied by squatters or informal settlements (Costello et al., 2009). "Informal settlements" are characterised by an absence of involvement by government in planning, building or infrastructure and lack of secure tenure. They often occupy areas prone to hazards and may be cosndrede illegal. At the other end of the wealth spectrum, there are those seeking environmental amenity through coastal canal estates, riverside and bush locations - areas that are often at greater risk from floods and fires (Handmer and Dover, 2007).

Exposure is a necessary but not sufficient condition for impacts. For exposed areas to be subjected 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 (Cutter and Emrich, 2006; see chapter 2.2). For example, those whose livelihoods are weather dependent or whose housing offers limited protection from weather events will be particularly susceptible to harm (Dodman and Satterwaite, 2009). Others with limited capacity to recover include those with limited personal resources for recovery or with no access to external resources such as insurance or aid after an event, and those with limited personal support networks (Handmer and Dovers, 2007). Knowledge, health and access to services of all kinds including emergency services and political support help reduce both key aspects of vulnerability.

Refugees, internally displaced people 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 (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.

_________START BOX 4-2 _________

Box 4-2. Extreme Impacts and Successful Paths to Adaptation

The Montreal protocol is often provided as a successful example of adaptation. The depletion of the ozone layer mostly by chlorofluorocarbons (CFCs) and also halocarbons was analysed and attempts to solve it are showing encouraging results (Eyring *et al.*, 2007), although a reduction in NO_2 emissions would ease both Ozone layer recovery and climate change (Ravishankara *et al*., 2009). Without saying that it was straightforward, it was at least eased by the fact that it was addressing a single issue: the use of CFCs and halocarbons in industry, for which substitutes were available. In contrast climate change issues are much more complex; they have multiple roots embedded at the heart of human activities: agriculture, forestry, deforestation, waste, energy supply, transport, residential heating/cooling and industry (IPCC, 2007). Governments are trying to find solutions to contain the global warming to +2°C and this will be difficult (Meinshausen et al., 2009). Even if this can be achieved, a 2°C rise will have severe consequences in terms of extremes (see chapter 3). In some situations (extreme events or extreme impacts) adaptation may no longer be an option and might lead to extreme impacts such as evacuating the population of a selected region, abandoning a whole economic sector in a specific location, or the extinction of species.

This is specifically of concern for some societies and cultures living in places that are highly sensitive to climate change: e.g. populations living in low elevation areas (especially islands) whose territories may be submerged by sea level rise or by storm surges; populations living in areas where water supply during the dry season is provided by small glaciers; agriculture in dryland areas facing decreases in precipitation and thus increasing risk of crop failure. Tourism is a sector of activities which, in some locations, can be deeply affected by extreme events or by extreme impacts from incremental changes. This is true for tourism depending on beaches facing high erosion from sea level rise, diving activities where coral bleach may decrease the attractiveness of a specific diving spot; but also low elevation ski resorts (IPCC, 2007b), where warming temperatures will reduce the length of, or confidence in, the snowy season or increase the variability in snow precipitation (see 4.4.2.4).

In our globalised world, individuals can migrate and economic sectors may change to seek alternative forms of revenue. However, this is not the case of several ecosystems, e.g. polar and mountainous ecosystems or coral reefs (Hoegh-Guldberg, 2007, see Section 4.5.9 and 4.3.3.1) where there are temperature thresholds above which survival of selected species is no longer possible. In these cases the only solution relies on international efforts in mitigating GHG.

Climate change share many aspects with unsolved issues (white area in Figure 4-3). In his popular book "*Collapse*", Jared Diamond (2005) discusses several examples of past collapses of societies. Some of the examples chosen are debated by the scientific community. For example, there are disagreements on the cause of collapse of the Maya civilization, which may not have collapsed from careless deforestation (McNeil et al., 2010), but from a severe drought (Peterson and Haug, 2005). Other scientists challenge the supposed causes of the collapse of the past civilization of Easter Island (Rapa Nui). It has been suggested that the collapse followed the removal of all trees for building statues, but the collapse may have in fact resulted from an invasion of Pacific rats introduced to the island by Polynesian colonists (Hunt and Lipo, 2007). The main trigger, which seems unchallenged, for the collapse of the Anasasi society was a prolonged drought (Benson, Petersen and Stein, 2006). Other authors argue that the only options for avoiding collapse in the cases of the Anasasi, Rapa Nui, Maya and the Sumerians civilizations was population control (Good and Reuveny, 2009). Although scientists may disagree on the causes, nobody disputes the fact that these societies have collapsed. In some cases we may never know why and however as interesting it might be, the reasons cannot necessarily be transposed to our globalised world. All the societies which are described in Diamond's book were isolated societies (Good and Reuveny, 2009).

[INSERT FIGURE 4-3 HERE:
Figure 4-3: Path for Successful Problem Solving in Past Societies]

Beyond the reasons for past collapses, the paths that lead to successful or collapsing societies are more interesting. Current political approaches in dealing with climate change share many aspects with past cases where no attempts were made to solve the problem. Figure 4-3 provides examples of processes which lead to successful societies or to their collapse. Successful paths required either that the threat was anticipated or that it was perceived, or decisions were made to take action and the capacities and time available were sufficient to solve the issue.

At the other extreme a threat might not be perceived (because it is *imperceptible,* at least with the technology available) or because the process is so slow that it remains unnoticed until it is too late (*creeping normalcy or landscape amnesia*) (Diamond, 2005). In these cases, decision makers cannot be blamed, they did not know until it was too late.

The threat due to climate change is not part of these two extremes. Clearly it was not anticipated when the industrial revolution started that GHG may lead to climate change, but the issue is now well known. This corresponds to the range of situations in the white area (Figure 4-3). Aside from the questions about having enough time, capacities and funds to solve this challenging threat; the issue is: Are we attempting to solve it? And if not, why not? Several reasons from past collapses where decisions makers failed to even attempt to solve the issue are listed below and have similarities with the approaches taken in dealing with climate change:

a) Rational behaviour
Decision makers employ correct reasoning, but perpetrators taking advantage of the situation for personal benefits over common welfare and know that they will get away either because there is no law or that the law is not enforced. They feel safe because they are few in number, while the losses are spread over a large number of individuals.

b) Detachment between decisions and consequences
Decision makers are not affected by the consequences. The distance can be spatial (e.g. distance between GHG emissions and impacts from climate change), or temporal (e.g. future generations).

c) Tragedy of the commons
This describes a situation in which individuals or group act in their short-term interests to deplete a common access resource, rather than managing the resources for longer term gain. Consider a situation in which many consumers are harvesting a communally owned resource, e.g. timber: "if I don't cut that tree, someone else will anyway, so it makes no sense for me to refrain from deforesting". One obvious solution comes from collective action by for example governments or outside forces to step in and to enforce quotas (Hardin, 1968; Hardin, 1998).

d) Irrational behaviour
Reluctanance to abandon policy (or change minds) in the face of strong evidence that we should is often termed: "persistence in error", "wooden-headedness", "refusal to draw inference from negative signs", "mental standstill, or stagnation" (Diamond, 2005). In Figure 4-3 the successful paths, when anticipation is no longer an option, are to perceive new threats (meaning capacity in monitoring), the willingness to take action and attempt to solve the issues and finally to have the necessary funds and capacities (technologies, know-how) to adapt.

________ END BOX 4-2 ________

4.2.3.3. Impacts on Ecosystems

Even without considering the role of climate change, ecosystems are under significant threat. We are currently experiencing the sixth major biodiversity extinction and the first from human origins (Wilson, 1999). The current rate of species extinction is substantially enhanced by human activities.

Climate change will exacerbate the effects of land use and cover change; modify water regimes; and deposit anthropogenic nutrients (mainly nitrogen) into the environment. Wildlife may have a significant increase of exposure to toxic and foreign substances, hunting and exploitation.

The frequency and magnitude of extreme events is projected to increase (IPCC WGI, 200) and there is a risk that impacted ecosystems will never recover fully, with far-reaching consequences for human wellbeing (Cardoso, et al., 2008). Extreme events have consequences which are difficult to predict, given that such situations are often unprecedented. Extreme events could include, among other possibilities: sudden and transient temperature changes, rapid retreat of sea- and lake ice, bouts of abnormally intense or lengthy precipitation or extended droughts, wildfires, the sudden release of water from melting glaciers, and slumping of permafrost. These 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).

Increased frequency of large-scale disturbances caused by extreme weather events will cause increasing gaps and an overall contraction of the distribution range for species habitat. This will be particularly evident in areas with a relatively low level of ability for sustainability (Opdam and Wascher, 2004). On the basis of mid-range climate-warming scenarios for 2050, 15 to 37% of species in a sample of regions and organism groupings will be 'committed to extinction' (see Thomas, 2004).

Extreme events can cause mass mortality of individual species and contribute significantly to determining which species exist in ecosystems (Parmesan et al., 2000). For example, drought plays an important role in forest dynamics, a major influence of the mortality of trees in the Argentinean Andes (Villalba and Veblen, 1997); North American woodlands (Breshears and Allen, 2002; Breshears et al., 2005); and in the Eastern Mediterranean (Korner et al., 2005b). Drought can also affect wildlife where, in Monteverde preserve (Costa Rica), 40% of the 50 local amphibian species have become extinct since 1983 (Easterling et al., 2000) due to three severe droughts associated with El Niño events (Easterling et al., 2000).

Loss of habitat due to hurricanes can also lead to greater conflict between animals and humans. Hurricanes can cause widespread mortality of wild organisms, and their aftermath may cause more declines due to the loss of resources required for foraging and breeding, creating competition between species (Wiley and Wunderle, 1994). For example, fruit bats (*Pteropus spp.*) descended 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]. Increased storm and other extreme events will also disturb 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]

Prior to the 1993 flood in the Upper Mississippi River floodplain, the ecosystem 'Quercus' constituted for 14% of the total number of trees and 28% of the total basal area, where as Carya only constituted for 10% of the total number of trees and 2% of the total basal area. During the post-flood recovery period through 2006, Quercus only made up 4% of the trees and 17% of the basal area. In the same period, Carya recovered greatly and made up 11% of trees and 2% of the basal (Yin et al., 2009).

An increase in heat leads to an increase of nitrogen in summer, influencing the effect of heat waves. Field experiments suggest that heat waves, though transient, could have significant effects on plants, communities, and ecosystem nitrogen cycling (Wang et al., 2008). Experimental and observational data have shown that crowberry (*empetrum)* can be damaged heavily by recurrent extreme winter warming, but flourish from an increase in the levels of nitrogen in the soil during summer warming (Aeryt, 2010)

Warming temperatures decreases net ecosystem carbon dioxide exchange (NEE) by inducing drought that suppresses net primary productivity. This is because the drying of the soil limits the capacity of the trees to absorb CO_2. Two years are required for NEE to recover to levels measured before warming. More frequent warm years may lead to a sustained decrease in carbon dioxide uptake by terrestrial ecosystems (Arnone et al., 2008). As a result, over the next 50 to 100 years the warming and drying of the Eastern Amazonia is expected to contribute significantly to climate change. A suggested solution is to breed trees with a deeper root system in order to absorb more moisture (Fisher, *et al*., 2007). 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 (century-scale) implications for vegetation, particularly if accompanied by drought conditions.

Animals are affected in many different ways. An extreme flood event affected a desert rodent community (that had been monitored for 30 years) by: inducing a large mortality rate; eliminating the advantage of previously dominant species; reseting long-term population and community trends; altering competitive and metapopulation dynamics; and rapid, wholesale reorganization of the community (Thibault, *et al*., 2008). Climatic extremes appear to influence juvenile survival in large mammal species, primarily during winter (Milner et al., 1999). Single extreme temperature events influence the adult sex of turtle, as this is determined by the maximum temperature experienced by the growing embryo (Bull, 1980 cited in Easterling et al., 2000). The gradual northward and upward movement of a given butterfly species' range since 1904 is likely due to the effects of a few extreme weather events (mainly extreme warm and/or dry years) on population extinction rates (Parmesan, 2006).

4.2.4. Detection and Attribution of Climate Change Impacts

Detection and attribution of climate change impacts can be defined and used in a 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). This material is reviewed in Chapter 3.

IPCC (2010) sets out four methods that have been used in detection and attribution of climate change impacts. There may be some overlap between the four methods.

"Single-step" attributions are assessments that are based on explicitly modelling the response of the variable to external forcings and drivers (see 3.2.2.3). 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 modelled (e.g. hydrological cycle; Barnett et al., 2008) or reasonably described empirically (e.g. area burnt by forest fires; Gillett et al., 2004).

"Multi-step" attribution to external forcings "comprise assessments that attribute an observed change in a variable... to a change in climate and/or environmental conditions". The climate or environmental change would separately be attributed to external drivers (see 3.2.2.3; IPCC, 2010). Using this approach, changes within many physical (e.g. glaciers, river flow, coastal erosion) and biological systems (e.g. polar bear behaviour, 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; Dauufresne et al., 2004; Root et al., 2003; Parmesan and Yohe, 2003; Menzel et al., 2006; Parmesan, 2006; Richardson and Schoeman, 2004; Edwards and Richardson, 2004; Root et al., 2005; Gillett et al., 2004; Menzel et al., 2006).

The third and fourth methods are "Associative patterns attribution" and "Attribution to a change in climatic conditions" (IPCC, 2010).

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 flooding or 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; see Chapter 3).

There is considerable evidence that economic losses from weather-related disasters are increasing, as evident from Figure 4-4 below (Munich Re, 2010; Swiss Re 2010; UN-ISDR, 2009). The principal challenge is the attribution to climate change of both the occurrence of and losses from extreme events. Changes in impacts over time need to be controlled for exposure and vulnerability. 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. See Section 4.3.2.2 for a discussion of this with respect to cyclones.

[INSERT FIGURE 4-4 HERE:
Figure 4-4: The Total Economic Losses and Insured Losses from "Great Weather Related Disasters" Worldwide (1950-2010, adjusted to present values)]

Most studies of disaster loss records attribute these increases in losses to increasing exposure of people and assets in at-risk areas (Miller et al., 2008), and by underlying societal trends - demographic, economic, political, social - that shape our vulnerability to impacts (Pielke et al, 2005; Bouwer et al., 2007). A few studies claim that an anthropogenic climate change signal can be found in the records of disaster losses (Mills, 2005; Höppe and Grimm, 2009; Malmstadt et al., 2009; Schmidt et al., 2009). Attempts have been made to normalize loss records for changes in exposure and wealth. This allows detection of observed changes in weather hazard rather than the disaster impact. The weight of evidence is that no long-term trends can be found in normalized losses that can be attributed to climate change. This is reasonably consistent when data are aggregated for different types of weather hazards, and across larger geographic areas (Choi and Fisher, 2003; Miller et al., 2008; Crompton and McAneney, 2008; Neumayer and Barthel, 2010).

The absence of climate change induced trends holds for tropical and extra-tropical storms and tornados (Boruff et al., 2003; Pielke et al., 2003; Raghavan and Rajesh, 2003; Pielke et al 2008; Miller et al 2008; Schmidt et al., 2009; Zhang et al., 2009; Barredo, 2010; see also Section 4.XX). Increases found in hurricane losses in the USA since the 1970s (Schmidt et al., 2009; Miller et al., 2008) are likely related to the natural variability observed since that time (Miller et al., 2008; Pielke et al., 2008). An exception is the study by Nordhaus (2010), who finds a significant increase in tropical cyclone losses in the US since 1900, but normalized for national level GDP, rather than exposure and wealth increases that have been higher locally (Pielke et al., 2008; Schmidt et al., 2009).

It also holds for flood losses (Pielke and Downton, 2000; Downton et al., 2005; Barredo, 2009; Hilker et al., 2009); although some studies did find recent increases in losses, related to changes in intense rainfall events (Fenqing et al., 2005; Chang et al., 2009). For precipitation related events (intense rainfall, hail and flash floods), the picture is more diverse. Some studies suggest an increase in damages related to a changing incidence in extreme precipitation (Changnon, 2001; Changnon, 2009a), although no trends was found for losses from flash floods and landslides in

Switzerland (Hilker et al. 2009). Similarly, a study of normalized damages from bushfires in Australia also shows that increases are due to increasing exposure and wealth (Crompton et al., 2010).

There is no conclusive evidence that anthropogenic climate change has lead to increasing losses, and increasing exposure of people and economic assets is *virtually certain to be* the major cause of the long-term changes in economic disaster losses. This conclusion depends on data availability (most data are available for developed countries); type of hazards studies (most studies focus on windstorms, where few anthropogenic changes have been established in the hazard – see Chapter 3); and the processes used to normalize loss data over time, Different studies use different approaches to normalisation, and most normalization approaches take account of changes in exposure, but use only partial measures of wealth for vulnerability trends which is questionable. Different approaches are also used to handle variations in the quality and completeness of longitudinal loss data. These are areas of potential weakness in the methods and conclusions of longitudinal loss studies and more empirical and conceptual effort is needed. Nevertheless, the studies mentioned above show similar results, although they have applied different datasets and methodologies. 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.

4.3. 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 by 17-fold in the same interval, in inflation-adjusted monetary units (Mechler and Kundzewicz, 2010). Between 1980 and 2004 the total costs of extreme weather events totaled US$1.4 trillion, of which only a quarter were insured (Mills, 2005). 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 (see Section 4.2.2; Field et al., 2009).

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 (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 6.9 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 (Aggerwal and Singh, 2010).

In much of the developed world, the societies are ageing, hence more sensitive to weather extremes, such as heat wave (Hennessy et al., 2007).

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)

In general, a given population living in a hazard prone area is not hit every year by hazardous events. The average number of people yearly exposed to hazards is known as "physical exposure" and mathematically can be obtained by multiplying the number of people living in hazard prone area by the frequency of occurrence of a selected hazard per year (Peduzzi, et al., 2009b). For example a population of one million, exposed in average every five years, has a physical exposure of 200,000. This is useful for comparison purpose and for computing insurances primes: For crisis management, this is not appropriate as the level of assistance should be designed for the one million exposed. In some locations, the frequency can be higher than 1, for instance the north of Philippines is - on average - hit several times per year by tropical cyclones. In limited amount of cases the physical exposure can be higher than the population living in hazard prone area.

Population exposure to hazards is fluctuating quantitatively depending on changes in demographics and hazard frequency (IFRC, 2009). Qualitatively it changes with exposure to types of hazards and to their intensity, for example categories of cyclone hazard or rier and costal flooding (Check Alcantra-Ayala, 2002).

The world population is currently increasing at a rate of about 80 million people per year. The population increased from 4 billion in 1970 to 5.3 and 6.9 billion in 1990 and 2010 respectively. UN projections for 2030 are up to 7.8 billion (United Nations Population Division, 2009). This change in population size will influence the exposure to hazards. More than 50% of the population is now urban. Urban populations are usually less vulnerable to hydro-meteorological hazards (UN, 2009), however, one shouldn't forget that about a third of the urban population lives in informal settlements, and thus more vulnerable to floods and tropical cyclones (Satterthwaite et al., 2007; also see section 4.3.4.2).

4.3.2.1. Issues in Unveiling Trends

International losses databases such as EM-DAT, NatCat and Sigma (maintained by CRED, Munich Re and Swiss Re respectively) present an increase in reported disasters through time. However, we see an increase of reported Tropical Cyclone disasters (from 21.7 to 63). One should not too quickly conclude that the number of disasters is increasing. There are four possibilities that may explain this increase: it could be due to improved access to information, due to higher population exposure, due to higher vulnerability, or due to higher frequency and/or intensity of hazards (Dao and Peduzzi, 2004; Peduzzi *et al*. 2009). To better understand this trend, one cannot use these international loss databases and other solutions need to be explored.

[INSERT TABLE 4-1 HERE:
Table 4-1: Trend of Reported Disasters from Tropical Cyclones Versus Events as Detected by Satellite for the Last Four Decades. The percentage of reported disasters increased three-fold.]

It is important to note that due to uncertainties in the significance of the role for each of these four variables, a vulnerability and risk trend analysis cannot be performed based on reported losses from EM-DAT or Munich Re. Here the analysis is only based on figures derived from modelling; they are independent from information reported by international database. It uses values modelled based on intersection between tropical cyclones footprints (events detected by satellite and footprints modelled by UNEP/GRID-Europe) and population distribution models based on Landscan (2008)[2] but extrapolated to reflect the population distribution from 1970 to 2030.

[INSERT FOOTNOTE 2 HERE: LandScan (2008)™, High Resolution global Population Data Set ©UT-Battelle, LLC, operator of Oak Ridge National Laboratory, http://www.ornl.gov/sci/landscan/ extrapolated for 1970 to 2010 by UNEP/GRID-Europe.]

4.3.2.2. Human Exposure to Tropical Cyclones by Region

There are currently an estimated of 1.15 billion people living in tropical cyclone prone areas. The physical exposure (yearly average number of people exposed) to tropical cyclones is estimated to 122.7 million (Peduzzi et al. 2011). Computing trends in physical exposure requires information on both hazard frequency and demographic changes. Chapter 3 (3.4.4) provides detailed information on projected changes in tropical cyclone hazards, but a brief summary is provided here. For exposure, only the change in the number of tropical cyclones that intersect with population is relevant. By modelling past tropical cyclones detected between 1970 and 2009 and intersecting with populations using Geographical Information Systems (GIS) it is possible to estimate the population exposed to tropical cyclones in the past 40 years (Peduzzi *et al.;* 2011). The number of time that countries are being hit by tropical cyclones is relatively steady (between 140 and 155 countries per year on average[3], see Table 4-2 (Peduzzi et. al. 2011).

[INSERT FOOTNOTE 3: This is the number of intersection between countries and tropical cyclones. One cyclone can affect several countries, but also many tropical cyclones are only observed over the oceans.]

[INSERT TABLE 4-2 HERE:
Table 4-2: Average Physical Exposure to Tropical Cyclones Assuming Constant Hazard (in Million People per Year)]

In most oceans, tropical cyclones are *likely* to decrease in frequency (see Figure 4-3 and Section 3.4.4) except in North Atlantic where the uncertainties go both ways. At constant hazard, the physical exposure to tropical cyclones would increase by about 11.6% due to demographic factors only. However, with the projected lower frequencies, this increase might be limited to 7.9% (between 5.7 and 12.4%). On a less positive note, except in North Indian Ocean, tropical cyclone winds and related rainfall is *likely* to increase (see chapter 3.4.4 and Figure 4-5), meaning that population are *likely* to be exposed to higher intensities.

[INSERT FIGURE 4-5 HERE:
Figure 4-5: Forecast Changes in Tropical Cyclones Hazards Frequencies by 2030 (Source: Peduzzi et al. 2011; Review of Models Based on Knustson et al. 2010)]

The change in physical exposure will be very different from one region to anther. This is mostly due to differences in projected changes of population numbers and hazard activity. Given this last perspective, a further refining of the IPCC regions was made. For instance Asia was split into two parts: Asia I includes Asian countries influenced by tropical cyclones from North Indian Ocean, while Asia II includes Asian countries affected by tropical cyclones from north-west Pacific Ocean. Similarly the region islands were split in three parts: Caribbean, Indian Ocean, Pacific Ocean islands to account for the specificities of tropical cyclones trends in North Atlantic, South Indian Ocean and South Pacific Ocean.

In relative terms, Africa (i.e. mostly Madagascar and Mozambique) will have the main percentage increase in physical exposure to tropical cyclones and with projected higher intensities (see Figure 4-6), followed by South and Central America (i.e. central America, South America being only marginally hit by tropical cyclones). In absolute terms, Asia, with more than 113 million people exposed per year, has 92% of exposure to tropical cyclones. Thus this region will face the highest increase with more than 6.1 million per year for Pacific Asia and greater than 1.8 million per year for Indian Ocean Asia.

[INSERT FIGURE 4-6 HERE:
Figure 4-6: Forecast Changes In Tropical Cyclones Hazard Intensities by 2030 (Source: Peduzzi et al. 2011; Review of Models Based on Knustson et al. 2010)]

[INSERT FIGURE 4-7 HERE:
Figure 4-7: Forecast Changes in Tropical Cyclones Population Exposure (Source: Peduzzi et al. 2011)]

[INSERT TABLE 4-3 HERE:
Table 4-3: Average Physical Exposure to Tropical Cyclones as Observed and as Projected Assuming Change in Frequency (Median of all Models, in Million People per Year and Percentage Changes).]

Worldwide, the exposure by category is 77.7, 17.0, 5.0, 0.4% for tropical cyclones category 1, 2, 3 and 4 respectively. Also, several tropical cyclones can have a maximum of Category 5, population exposed to such category remains - hopefully - marginal. The average (1970 - 2009) percentage of population exposed for the different tropical cyclones Saffir-Simpson categories are provided in Peduzzi et al. (2011).

[INSERT TABLE 4-4 HERE:
Table 4-4: Average Percentage Exposure to Different Category of Tropical Cyclones by Regions (1970 - 2009) Sources: Peduzzi et al. 2011.]

Despite uncertainties in trends of tropical cyclones frequency, *it is virtually certain* that population exposure to tropical cyclone will increase in the next 20 years, as a result of demographic pressure and despite likely expected reduction in tropical cyclones frequency. How the forecast likely increase in intensity will affect risk is another question, where more researches are needed.

4.3.2.2.1. Exposure for floods by region

About 800 million people are currently living in flood prone areas and an average of 70.7 million of those is exposed yearly to floods (Peduzzi et al., 2011). Given the lack of complete datasets on past flood events and the lack of clear projections on future precipitation trends, it is difficult to estimate the trend in flood hazards. However, the exposure trend is clear with a steady growth and expected 21.4% increase between 2010 and 2030 (Table 4-5). Due to model constraints areas north of 60°N and south of 60°S, as well as catchments smaller than 1000 km^2 (typically small islands) are not modelled. The figures provided below correspond to river flooding.

[INSERT TABLE 4-5 HERE:
Table 4-5 Trend in Floods Physical Exposure (In Thousand People Per Year) (Peduzzi et al. 2011)]

4.3.2.2.2. Exposure for landslides triggered by precipitations by region

In 2010, about 53.7 million people lived in areas prone to landslides triggered by precipitations and it is estimated that more than one hundred thousand people are being hit by landslides every year (Peduzzi et al. 2011).

Given the lack of a complete dataset on past landslide events and the lack of clear projections on future precipitation trends, it is difficult to estimate the trend in precipitation-triggered landslide hazards. However, the exposure trend is clear with a steady growth and expected 23.8% increase between 2030 and 2010 (Table 4-6). Due to model constraints areas north of 60°N and south of 60°S are not included. It should be noted that change in climate conditions is not the only trigger for change in precipitation-triggered landslides. Landcover changes, especially deforestation, is also a major cause for higher landslides susceptibility (Peduzzi, 2009)

[INSERT TABLE 4-6 HERE:
Table 4-6: Trend in Floods Triggered by Precipitation Physical Exposure (In Thousand People Per Year) (Disaster Risk Index, *Nat. Hazards Earth Syst. Sci.*, 9, 1149–1159.)]

4.3.3. Observed and Projected Trends in Hazards and impacts, Changing Frequency of Different Intensities, and New Locations Affected

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 potentially increasing frequency and intensity (e.g. Lozano et al., 2004; Wang et al., 2008; Allan and Soden, 2008; 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 already 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 and extreme events (e.g. Bernier et al., 2007; Purvis et al. 2008; Hinkel and Klein, 2009) and this work is still ongoing (Nicholls et al., 2007). Coasts comprise several sedimentary environments and ecosystems such as beaches, seacliffs and 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. Coastal wetlands, coral reefs, and seagrasses

Coastal wetlands (saltmarshes, mangroves) are controlled by sea-level changes, with modeling studies (e.g. McFadden et al., 2007) indicating large global losses by 2080, depending on sea level rise rates. 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 (Loder et al., 2009).

Saltmarshes accumulate both organic and inorganic sediments and are graded landward from salt, to brackish, to freshwater assemblages. Climate change will force changes in their hydrodynamic and sediment dynamic regime, their biogeochemical conditions and their exposure to extreme events, with the effects considered to be more pronounced in brackish and freshwater marshes (Nicholls et al., 2007). While feedbacks between vegetation growth and sediment deposition tend to promote morphological equilibrium under constant sea level rise rates, observations/modeling suggest that changes in the rise rates may induce marshland losses; carbon accumulation has been found to be non-linearly related to both inorganic sediment supply and sea level rise rates, increasing with the rise rate until a critical threshold that limits the process and forces marsh drowning (Mudd et al., 2009). Simulation of the saltmarsh response to sea level rise (100 year predictions) suggests that under low 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 mostly to short-term sea level changes, whereas those in macro-tidal, wave protected coasts mostly to long-term changes (Kolker et al., 2009). Saltmarsh elevation and resilience has been found to be controlled by both groundwater (Cahoon et al., 2010) and surface water fluctuations; storm surges have been associated with substantial reductions of supratidal saltmarshes in back-barrier environments (Riddin and Adams, 2010). Finally, storm surge and wave energy propagation onto saltmarsh areas has been found to be sensitive to sea level, being greater in areas with increased relative sea level rise (McKee Smith et al., 2010).

Mangrove forests, found in sub-tropical and tropical coasts, may show both positive and negative responses to climatic changes and extremes, depending on site-specific factors (Saenger, 2002). Sediment surface elevations in mangrove forests are subject to biological controls (McKee, 2010), with precipitation/run off being also a significant factor (Eslami-Andargoli et al., 2009). Relative sea level rise may pose the greatest threat to mangroves, as most mangal sediment surface elevations do not appear 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 relative sea level rise (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). Storm surges and waves due to tropical cyclones have been found to have negative effects on both the sedimentary structure (Cahoon et al., 2003) and the spatial distribution of mangroves (Paling et al., 2008), with potential negative feedbacks on the resilience of mangal coasts (also see Chapter 8).

Coral reefs are subject to a variety of impacts in relation to climate change (James and Crabbe, 2008). Although coral reefs have shown some resilience to climatic (and anthropogenic) changes (McClanahan e al., 2009), they could be subjected to increased strain, or even collapse above some critical thresholds (Veron et al., 2009), introducing 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). In comparison, high sea water temperatures promote bleaching and pose an extreme threat to the persistence of coral populations in the projected warming regime of the next few decades. Mass bleaching events have been found to be associated with extreme warm temperature anomalies (Miller et al., 2010), with bleaching depending more on the variability of sea surface temperature (SST) than its background values (e.g. Ateweberhan and McClanahan, 2010; Williams et al., 2010). It must be noted that although coral communities might be able to acclimatize in environments exhibiting significant temperature fluctuations (e.g. in the Persian-Arabian Gulf), they can still be threatened by habitat shortages brought about by climate-driven geochemical dissolution of the lithified seabed on which they rely for colonization (Purkis et al., 2010). Other extreme events, such as tropical cyclones and high energy storms, can also inhibit reef growth (Montagionni, 2005) by e.g. (a) enhancing sediment mobility and water turbidity (e.g. Lambrechts et al., 2010; Ouillon et al., 2010; Williams et al., 2010), (b) decreasing coral recruitment (James et al., 2008) and (c) increasing water flows past bleaching corals and, thus, affecting heat shock protein synthesis (Carpenter et al., 2010). Storms can also result in mechanical reef degradation (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 CO_2 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). Seagrass meadows can provide protection to adjacent coasts by attenuating storm waves (RiVAMP, 2010). At the same time, storms/storm waves can have significant impacts on seagrass meadows by (a) burying them under large volumes of sediments (Knudby et al., 2010), (b) promoting seed mortality (e.g. Ballestri et al., 2006) and (c) modifying seagrass community structure, with solid, deeply anchored root–rhizomes or rhizoid systems combined with a flexible or modular above-ground structure being able to better resist storm-driven perturbations (Cruz-Palacios and van Tussenbroek, 2005).

4.3.3.1.2. Human systems

Although coastal inundation due to sea level rise (and/or relative sea level rise) will certainly be a significant problem for coastal landforms and 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 thought to be associated with extreme sea levels due to tropical and extra-tropical storms (e.g. Ebersole et al., 2010; Mosumder et al., 2010) that will be superimposed upon the long-term sea level rise (e.g. Frazier et al., 2010). The impacts are considered to be more severe for large urban centers built on deltas and Small Island States-SIS (Wardekker et al., 2010; Love et al., 2010), particularly for those 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 protecting barrier islands and/or coastal wetlands that may attenuate surges, see e.g. Irish et al., 2010 and 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, recent studies (Nicholls et al., 2008; Hanson et al. in press) have assessed the asset exposure of port cities with more than one million inhabitants (in 2005). They demonstrated that large populations 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; these estimations, however, do not account for the potential construction of effective coastal protection schemes (see also Dawson et al., 2005). They also found that 2/3 of the projected exposure will be due to socio-economic reasons (e.g. population changes/urbanization and economic development), with the exposure growth rate being more rapid in developing countries, particularly their urban centers which are the most common destinations of environmental migration inflows (e.g. Adamo, 2010). 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 cities 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.]

Although the overall growth of economic globalization may be also affected by climatic extreme events (e.g. Oh and Reuveny, 2010; Fink et al., 2010), the most immediate effects are *likely* to be associated with the coastal infrastructure/services and, particularly, with ports, the key-nodes of 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, precipitation/river floods and storm surges. All coastal modes of transportation are considered vulnerable, but exposure and impacts will vary e.g. by region, mode of transportation, location/elevation and condition of transport infrastructure (National Research Council, 2008; UNCTAD, 2009b). Coastal inundation due to storm surges and river floods can affect terminals, intermodal facilities, freight villages, storage areas and cargo and disrupt intermodal supply chains and transport connectivity (see Figure 4-8). These effects would be of particular concern to Small Island States (SIS), whose transportation facilities are mostly located in the low elevation coastal zones LECZ (UNCTAD, 2009b; for further examples, see Love et. al. 2010). One of the most detailed studies on the potential impacts of climate change on transportation systems was carried out in the US Gulf Coast (CCSP, 2008). According to this study, a sea level rise of ~1.2 m could inundate more than 2,400 miles of roadway, over 70% of port facilities, 9% of the operational rail miles and 3 airports, while more than 50% of interstate and arterial roads, 98% of port facilities, 33% of rail miles and 22 airports in the US Gulf coast would be affected by a ~5.4 m storm surge (CCSP, 2008). Experts at an UNCTAD Èxpert meeting (UNCTAD 2009b) highlighted the need for an increased focus on responding to the climate change challenges, 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, has tasked its Port Planning and Development Committee to undertake the necessary studies (see IAPH, 2009; Becker et al., 2010).

[INSERT FIGURE 4-8 HERE:
Figure 4-8: Freight Handling Port Facilities at Risk from Storm Surge of 5.5 and 7.0m in The US Gulf Coast (Source: CCSP, 2008)]

Housing in coastal areas will also be severely affected by climate change-driven extremes (e.g. Maunsell, 2008). Lloyd's (2008) has considered flood hazard for coastal properties at a number of locations around the world due to sea level rise 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. Neumayer and Barthel (2010) have not, however, discerned any significant upward trends in normalized disaster damages over the period 1980–2009 globally, regionally, for specific disasters or for specific disasters in specific regions

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. 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 relative sea level rise, 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 (e.g. Rigall-Torrent et al., 2010; Pacheco and Lewis-Cameron, 2010). 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) (also see Section 4.4.5.3).

4.3.4. Observed and Projected Trends in Human Systems and Sector Vulnerability to all Climatic Extremes and to Specific Types of Hazards

4.3.4.1. Global and Regional Trends in Vulnerability Factors

Section 4.3.2 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.

One indicator of trends in vulnerability may be provided by the impacts of climatic hazards, with appropriate controls for changes in exposure, data quality, and the value of the assets exposed. However, as discussed in Chapter 2, care is needed in ascribing impact trends to vulnerability. Another approach is to examine trends in factors that increase or decrease vulnerability.

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 (see section 4.2.2).

Overall vulnerability appears to be fairly stable (UNISDR, 2009b), although this general statement conceals a diverse range of trends including areas and groups where the vulnerability is decreasing. Some of these are discussed below. Others include lack of good governance (Hardor and Paniella, 2009), and the absence of ready access to education and health services (Haines et al., 2006).

Dispossession by war or civil strife

Refugees and those driven into areas where livelihoods are marginal are susceptible to impact from extreme events are often the most vulnerable to the impacts of extreme events because they are cut off completely from coping mechanisms and support networks. As a result of war or civil strife nearly half the world's countries (sixty countries) are directly linked to uprooted populations with people being forced to flee (Handmer and Dovers, 2007). 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). Those who are displaced for years also suffer nutritional shortfalls as well as physical and mental incapacities increasing vulnerability to extreme events (Toole, 1995).

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 tend to fall and children may grow at a slower rate due to nutritional shortfalls following disasters (UNISDR, 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 is 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 four 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 Global assessment report on disaster risk reduction, 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 (see section 4.4.5).

Small island countries (from Global assessment report on disaster risk reduction, 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." (UNISRD, 2009; pg. 3)

Emergency support (from Global assessment report on disaster risk reduction, 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." (UNISRD, 2009; pg. 4)

Ecosystems
The Millennium Assessment (2005) 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). Recent experimental evidence from central European grassland suggests that annually recurrent 100-year and 1000-year extreme drought events might have no effect on primary productivity there, whereas other services such as gas exchange, nutrient cycling and water regulation are clearly stimulated (Kreyling et al., 2008)

4.3.4.2. Examples of Observed and Projected Trends in Human and Sector Vulnerability

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 and changes in the property, lives and systems using the water resource or exposed to water-related hazard (Aggarwal and Singh, 2010; see Section 4.4.2). 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. 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 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 in recent years (see Figure 4-9). 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 4-9 HERE:
Figure 4-9: Water-Related Disaster Events Recorded Globally, 1980 to 2006 (Source: 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 300,000 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).

__________START BOX 4-3 ________

Box 4-3. Extraordinary Heat Wave in Europe, Summer 2003

The extraordinarily severe heat wave over large parts of the European continent in the summer of 2003 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 (Schär and Jendritzky, 2004). 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).

Impacts of the heatwave were mainly health- and health-service related, with excess deaths of about 35,000 (Kosatsky, 2005). Elderly people were among those most affected (WHO, 2003; Kovats and Ebi, 2006), but deaths were also associated with housing and social conditions. For example being socially isolated or living on the top floor. Electricity demand increased with the high heat levels. The impacts were combined with those form a drought created stress on health, water supplies, food storage and energy systems – e.g. reduced river flows reduced 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). 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 (uninsured) economic losses for the agriculture sector in the European Union were estimated at €13 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). 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).

_________END BOX 4-3________

4.3.5. *Observed Trends in Ecosystem Vulnerability to all Climatic Extremes and to Specific Types of Hazards*

Extreme climatic events have increased in frequency and magnitude, but their ecological impacts are far 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 to 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. Tall-grass prairie net ecosystem carbon dioxide exchange levels decreased in both the extreme warming year (2003) and the following year 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 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 (USA) 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 (Spain) , 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).

Cyclones are discussed elsewhere in Chapter 4.

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).

An absence of information does not mean that there are no adverse impacts from extreme events on ecosystems in developing societies. (Because of a lack of research or perhaps lack of papers in English, there is relateively little published on climate extremes and on ecosystems. It is likely that the research in developing countries was 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 is not yet available for citation 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).

4.4. System- and Sector-Based Aspects of Vulnerability, Exposures, and Impacts

4.4.1. Introduction

In this sub-section, existing studies which assessed impacts and risks of extreme events or extreme impacts are surveyed for each major affected sectors/systems. Sectors/systems considered are: water, ecosystem, food, settlements/industry/infrastructure, and human health. 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, stakeholders including policymakers could make use of the knowledge for 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 and future risks of extreme events is evaluated and the findings of major research are introduced by sectors/systems.

[INSERT TABLE 4-10 HERE:
Table 4-10: Links between sectors, exposure, vulnerability and impacts]

4.4.2. Water

This section assesses the literature on potential future changes in extreme aspects of water, focusing on water supply and floods (coastal floods are covered in Section 4.4.2.4). The literature is assessed at the "local" scale (the scale at which water supplies and floods are generally managed), the national scale and the international scale.

In terms of water supply, an extreme event is one which threatens 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, deterioration in water quality, an increase in demand, or an increase in vulnerability to water shortage. Future reductions in river flows or groundwater recharge may be a result of climate change (see Section 3.5.1.3), of changes in catchment land cover, or changes in upstream interventions. A deterioration in water quality may be driven by climate change (as shown for example by Whitehead et al. (2009), Delpla et al. (2009) and Park et al.(2010)), change in land cover or upstream human interventions. An increase in demand may be driven by demographic, economic, technological or cultural drivers (see Section 2.6.4). 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 (see 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).

Few studies have so far been published into the effect of climate change on the impacts of drought in water resources terms at the local catchment scale. Virtually all of these have looked at water system supply reliability during a drought, or the change in the yield expected with a given reliability, rather than indicators such as lost production, cost or well-being. Changes in the reliability of a given yield, or yield with a given 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; Kim et al., 2009; Takara 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 future changes 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.

There have been several continental or global scale assessments of potential change in hydrometeorological drought indicators (see Section 3.5.1.3), but relatively few on measures of water resources drought or drought impacts. This is because these impacts are very dependent on context. The one published large-scale assessment (Lehner et al., 2006) used a generalised drought deficit volume indicator, calculated by comparing simulated river flows with estimated abstractions for municipal, industrial and agricultural uses. The indicator was calculated across Europe, using two climate change scenarios and assuming changes in abstractions over time. They showed substantial changes in the future return period of the present 100-year return period drought deficit volume (Figure 4-11a). 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 (Figure 4-11b). In Southern and Western Europe, changing withdrawals alone only increases deficit volumes by less than 5%, whereas the combined 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.

Climate change has the potential to change river flood characteristics through changing the volume and timing of precipitation, by altering the partitioning of precipitation between snow and rain and, to a lesser extent, by changing evaporation and hence accumlated soil moisture deficits (Section 3.5.2.3). Changes in catchment surface characteristics (such as land cover), floodplain storage and the river network can also lead to changes in the physical characteristics of river floods (e.g. along the Rhine: Brontsert et al., 2007). 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. There have, however, been very few studies which have looked explicitly at the human impacts of flooding, rather than changes in flood frequencies and magnitudes (Chapter 3). One study has so far looked at changes in the area inundated in floods with defined return periods (Veijalainen et al., 2010), showing that the relationship between change in flood magnitude and flood extent depended strongly on local topographic conditions.

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 four and five 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 precipitation outputs from climate models and rainfall-runoff models for a sample of UK catchments. 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 4-11 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.

At the global scale, two studies have estimated the numbers of people affected by increases (or decreases) in flood hazard. Kleinen and Petschel-Held (2007) calculated the percentage of population living in river basins where the return period of the current 50-year return period event reduces, for three climate models and a range of increases in global mean temperature. With an increase in global mean temperature of 2°C (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. Hirabayashi & Kanae (2009) used a different metric, counting each year the number of people living in grid cells where the flood peak exceeded the (current) 100-year magnitude, using runoff as simulated by a high-resolution climate model fed through a river routing model. Beyond 2060, they found that at least 300 million people would be affected by substantial flooding even in years with relatively low flooding, with of the order of twice as many being flooded in flood-rich years. This compares with a current range (using the same index) of between 20 and 300 million people. The largest part of the increase is due to increases in the occurrence of floods, rather than increases in population.

[INSERT TABLE 4-11 HERE:
Table 4-11: 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.]

[INSERT FIGURE 4-11 HERE:
Figure 4-11: Change in Indicators of Water Resources Drought across Europe by the 2070s (Source: Lehner et al., 2006)]

4.4.3. Ecosystems

Extreme events could have serious impact on terrestrial ecosystems. Extreme events, such as high temprature, severe drought, and floods etc., could exceed the physiological limits of some species, damage their habitats or food supply or result in bio-diversity loss.

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, GWII, section 4.4.2)

Experimental evidence has shown, that extreme drought events advance flower onset (the mid-flowering date) and extend the flowering period of Central European plant species (Jentsch et al. 2009). The magnitude of the shift (around 4 days) is remarkable when compared with findings from long-term observational datasets accounting for gradual warming over recent decades: warming has advanced the first flowering date of plants by 4 days, 1°C on average in the temperate zone (Memmott et al., 2007). On short-term time scales, extreme weather events might be even more powerful than gradual warming in disturbing the synchronization between organisms (e.g. Both et al., 2006) and community organization, because their occurrence and return interval is much less predictable and the vigor of their effects may reach a decadal scale of warming. Furthermore, interaction effects of extreme weather events with plant diversity are emerging as a one of the most challenging research frontiers in studying shifts in plant phenology.

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 et al., 2004) with some exceptions (Mouillot et al., 2003; see also IPCC, AR4, GWII, section 4.4.3)

Nonlinear system dynamics are ubiquitous. For example, internal feedbacks of ecosystems, such as fuel-triggered fire regimes, can interact with large-scale external forces, such as global weather patterns or restoration efforts, and trigger shifts to either alternative regimes or to novel trajectories. Nonlinear system dynamics imply that a systems' retransformation leads to novel conditions instead of prior structures and functions (e.g., ''hysteresis''; Beisner et al. 2003). This phenomenon has been documented, e.g., in Australia, where shifts of open dryland ecosystems to permanent woodlands occurred due to El Nino Southern Oscillation effects interacting with human land use dynamics (Holmgren et al. 2001). Often, nonlinerarity of ecosystem dynamics or regimes shifts is neither very obvious nor dramatic. For example, factors that undermine resilience slowly, such as eutrophication in resource-limited systems (e.g., Jentsch et al. 2002), disturbance mediated introduction of invasive species (Sharp & Whittaker 2003), or climate change (e.g., Jentsch & Beierkuhnlein 2003), can be responsible for altered successional trajectories. 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 and seabirds (see also IPCC, AR4, GWII, section 4.4.9)

The magnitude of impacts depends not only on the degree of warming but also on the number of species at risk, their physiological sensitivity to warming and their options for behavioural and physiological compensation. For example, warming will not only further depress lizards' physiological performance in summer, but will also enable warm-adapted, open-habitat competitors and predators to invade forests (Huey et. al., 2009). A model of avian evaporative water requirements and survival times during the hottest part of day reveals that the predicted increases in maximum air temperatures will result in large fractional increases in water requirements (in small birds, equivalent to 150–200% of current values), which will severely reduce survival times during extremely hot weather (Mc Kechnie et. al., 2010).

Climate change could trigger massive range contractions among amphibian and reptile species in the southwest of Europe. Araujo et al, 2006 projected distributions of 42 amphibian and 66 reptile species 20-50 years into the future under 4 emission scenarios. One model proposed by the Intergovernmental Panel on Climate Change and another three alternative climate models (HadCM3, CGCM2, and CSIRO2). They found that increases in temperature are not likely to constitute a major threat to amphibian and reptile species in Europe. Indeed, a global cooling scenario would be much worse. However, increases in aridity could trigger contractions in the distributions of nearly all species occurring in the southwest of Europe, including Portugal, Spain and France. Impacts in these three countries are not trivial because, together, they hold 62% of the amphibian and reptile species present in Europe. The high proportion of amphibian and reptile species occurring in these three countries is due to the key role played by the Iberian Peninsula as refugia against extinctions during past glacial periods. With projected climate changes these hotpots of persistence might be at risk of becoming hotspots of extinction (Araújo, et. al., 2006).

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, GWII, 4.4.10] Heat waves could also impact on: increase of likelihood of catastrophic avian mortality events (McKechnie, et al., 2010); decline of amphibians and reptiles in Europe (Arau´ jo, et al., 2006).

ENSO events could lead to some extremes that impact on ecosystems. For example, Hawaiian rainforests and dry forests exhibit asynchronous leaf phenology during seasonal and El Niño-driven drought. During dry seasons, dry forest NDVI showed decreasing greenness while rainforest NDVI showed increasing greenness. Dry forest NDVI was more tightly coupled with precipitation compared to rainforest NDVI. A reduction in clouds over the rainforest during dry periods may have increased solar radiation resulting in a dry season green-up. Rainforest green-up and dry forest browndown was particularly apparent during the 2002–2003 El Niño, which was a period of low precipitation and few clouds (Pau, et al., 2010).

The other example is that the timings of droughts and floods coincided with strong episodes in the activities of the ENSO phenomenon. Above-average rainfall often accompanied cold ENSO episodes and below-average rainfall warm ENSO events, contrary to past generalizations suggesting that warm ENSO events are only associated with above-average rainfall whereas cold ENSO events with below-average rainfall in equatorial East Africa (Ogutu et al., 2007). Both minimum and maximum temperatures were below-normal during cold ENSO episodes and above-normal during warm ENSO events. Rising temperatures and declining rainfall throughout the 1990s and early 2000s, with unprecedently prolonged and strong ENSO episodes, engendered progressive habitat desiccation and reduction in vegetation production in the ecosystem. This exacerbated the debilitating effects of adverse weather on local plant and animal communities, resulting in high mortalities of ungulates (Both, 2006).

Ecosystems provide essential services to maintain human life and quality of life, these include (among other things); water provision, waste composting, management of atmospheric and climatic elements, soil maintenance, pest control, pollination, habitat maintenance and biodiversity (Cork, 2001). Not only do ecosystems provide these services to support human lives and economies, they can also protect us from disasters and extreme weather.

Ecosystem services that are damaged or altered as a result of disaster may increase the chances of another extreme event occurring. A forest may protect an alpine settlement from avalanches, or a wildfire that consumes a forest depletes that ecosystem of its capacity to absorb CO^2 leading to further temperature increases and possibly a drought or another wildfire. However, disasters can also have positive impacts on ecosystem services. In the case of flooding, the moving water can bring essential nutrients to new areas of the ecosystem allowing it to thrive (DFID, 2005).

Biodiversity can limit the damages sustained on ecosystem services after a disaster as with more species present in a particular environment, the greater the opportunity for a species to survive the disaster and aid the ecosystem recovery process (Cairns, 1997).

4.4.4. Food Systems and Food Security

Food systems and food security can be affected by extreme events that impair food production and that impair food storage and delivery systems (food logistics). Some economies are dependant solely on food systems.

Changes in temperature and precipitation patterns will affect food production systems and food security. Combinations of high temperature and variable precipitation will impact plant growth, development, and grain yield. In a recent assessment of high temperature as a component of climate trends, Battisti and Naylor (2009) concluded that future high temperature events will cause major impacts on food security around the world. Future food security will depend upon adaptation of agronomic practices and genetic resources to cope with the extremes in high temperature and precipitation and our ability to match supply and demand under a changing climate. 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 in crops. As a result water is used at an increased rate linking it to a water shortage.

Extreme temperatures will have their greatest effect if they occur just prior to or during critical pollination phases of the crop (Hatfield et al, 2008, 2011). The impact is not universal across all crop species because of the duration and timing of the pollination phase of crop development but has been observed through numerous experimental studies throughout the world. Crop sensitivity and ability to compensate during later improved weather, will depend on the length of time for anthesis in each crop.

Extreme temperatures will have negative impacts on grain yield. (Kim et al., 1996; Prasad et al., 2006). For example, Tian et al. (2010) observed in rice that a combination of high temperatures (>35°C) coupled with high humidity, and low windspeed caused the panicle temperatures to be as much as 4°C higher than air temperature inducing floret sterility. Impacts of temperature extremes may not be limited to daytime events and Mohammed and Tarpley (2009) observed rice yields were reduced by 90% when the ambient temperatures were increased from 27 to 32°C. Diurnal max/min day/night temperatures of 40/30ºC (35ºC mean) cause zero yield. There are combinations of high temperature events wich are likely to negatively impact crop growth and yield. The effects of temperature extremes on a number of different crop species have been summarized in Hatfield et al. (2011).

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). In cool season crops, e.g., Brassica, high mean temperatures reduce the number of flowers and prolonged heat stress during seed development decreased yield (Morrison and Stewart, 2002). Both cool and warm season plants exposed to high temperatures will exhibit reductions in growth and seed production.

Drought causes yield variation and an example from Europe demonstrates that historical yield records show that drought has been the primary cause of interannual yield variation (Hlavinka et al., 2009). The scientific literature detailing the impacts of water deficits on crop production is voluminous and is beyond the scope of this report to provide a detailed review. 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, debris is 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 sells 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 to achieve adequate levels of production, 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, resulting in lessened food security (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).

Unless agricultural production is consumed where it is produced, it must be transported, and often processed and stored. This process is partly global and involves complex interdependent supply chains which are exposed to multiple hazards. At every step of the process, transport and associated infrastructure such as roads, railways, bridges, wharehouses, airports, ports and tunnels are at risk from direct damage from climate events. The processing and delivery chain is also at risk from disruption resulting from damage or blockages at any point of the chain. The threat of damage will rise with increased frequency and severity of extreme events, including extreme precipitation events (CSIRO 2007a). This could increase the vulnerability of the food logistics industry in the event of a disaster by reducing the amount of food available to consumers (Keating, 2010). The impacts could be severe in some countries like Australia which have only a few days supply of food available in storage and transport (Keating, 2010). Port and coast infrastructure are at particular risk when storm surges combine with rises in sea level. Rail operations could be increasingly compromised if, as predicted, climate change increases the frequency of lightning strikes.

4.4.5. Human Settlements, Infrastructure, and Tourism

4.4.5.1. Human Settlements

Settlements concentrate the exposure of humans, their assets and activities. In the case of very large cities these concentrations can represent a significant proportion of national wealth and may result in additional forms of vulnerability (Mitchell 1998). Flooding, landslides (UN/POP/EGM-URB/2008/16), storms, heat waves (Kovats and Aktar, 2008) and wildfires (ref) have produced historically important damages in human settlements. All these hazards are expected to increase with climate change. The massive concentration of economic assets and people creates the possibility of very large impacts, but also the capacity for recovery (Cutter et al., 2008). Coastal settlements are especially at risk with sea level rise and increases in coastal storm activity (see Case study 9.9 – Vulnerable coastal and mega cities).

At highest risk of impacts are the urban poor in informal settlements ((UN/POP/EGM-URB/2008/16; Douglas, 2009; MacDonald and Calow, 2009; Swiss Re, 2006). Worldwide, about one billion people live in informal settlements, and this proportion is growing at about twice the rate of formal settlements (ref). Informal settlements are also found in developed countries; for example there are about 50 million people in such areas in Europe (UNECE 2009). Occupants of informal settlements are typically more exposed to climate events with no or limited hazard-reducing infrastructure. The vulnerability is high due to makeshift housing and limited capacity to cope due to a lack of assets, insurance, and marginal livelihoods, with less state support and limited legal protection (Dodman and Satterthwaite, 2008).

The number and size of coastal settlements and their associated infrastructure has increased significantly over recent decades (ref). In many cases these settlements have affected the ability of natural coastal systems to respond effectively to extreme climate events, in turn increasing the exposure of coastal communities and assets at an accelerating rate (Emanuel, 2005). Small island states, particularly SIDS (see Case study 9.10), are likely to be very severely affected by climate change related extremes; and in some cases there may be a need to consider evacuation (ref).

Urbanization exacerbates the negative effects of flooding – expected to increase with climate change (see Case study 9.5) - through greatly increased runoff concentration peak and volume, the increased occupation of flood plains, limited waste management and inadequate drainage planning (Douglas, 2008; McGranahan, Balk and Anderson, 2007). These urbanization issues are universal but often at their worst in informal settlements which are generally the most exposed to flooding, and usually do not have the capacity to deal with the issues (Hardoy, Mitlin and Satterthwaite, 2001). Flooding regularly disrupts cities, and urban food production can be severely effected by flooding undermining local food security in poor communities (Aggarwal and Singh, 2010; Douglas, 2009). A further concern for low and middle income cities as a result of flooding is human waste, as most of these cities are not served by proper water services such as sewers, drains or solid-waste collection services (Hardoy, Mitlin and Satterthwaite, 2001).

Slope failure risk affects settlements in tropical mountainous areas especially if deforested (e.g. Vanacker et al. 2003), and hilly areas (Loveridge, 2010) especially following heavy prolonged rain (Case study section 9.1.1). Informal settlements are often exposed to high risk of slope failure as they are often located on unstable land, in the absence of engineering or drainage works (Anderson, Holcombe and Renaud, 2007). Informal settlements were disproportionatly impacted by landslides in Colombia and Venezuela in 2010 during unusual heavy rains associated with the La Niña weather phenomenon (Ref).

Cities can significantly increase local temperatures and reduce temperature drop at night (see section 9.3.1 - Case study 9.2). This is the urban heat island effect resulting from the large amount of heat absorbing material, building characteristics, and emissions of anthropogenic heat from air conditioning units and vehicles. Heat waves combined with urban heat islands (UHI) can result in massive death tolls with the elderly and outdoor workers being most vulnerable. When combined with climate change they pose a challenge to the future of major cities (e.g. London, Wilby, 2003a). In urban areas, heat waves have also negative effects on air quality and the number of days with high pollutants, ground level ozone suspended particle concentrations (Casimiro and Calheiros, 2002; Sanderson et al., 2003; Langner et al., 2005; Stevenson et al., 2006).

The frequency and severity of most forms of storms are predicted to increase (FitzGerald, et al., 2008; Hess, Malilay and Parkinson, 2008; Swiss Re, 2006; Chapter 3.XX). The destructive potential of cyclones is likely to increase set to develop, putting those in the increasing coastal populations at further risk (Emanuel, 2005). Storms generally result in considerable disruption and local destruction, but cyclones and their associated storm surges have destroyed modern cities (eg New Orleans and Darwin; Case study 9.1.2). Small island states probably have the highest risk due to exposure, capacity and because beach erosion leads to the loss of their land (McGranahan, et al., 2007.

4.4.5.2. Infrastructure

Climate-related extremes impact infrastructure, although detailed analysis of potential impacts are limited to a few countries (e.g. Australia, Canada; Holper et al., 2007), infrastructure types (e.g. power lines) and sectors (e.g. transport, tourism). Inadequate infrastructure also increases the impacts of climate events. Some infrastructure is likely to become inadequate as climate change alters the frequency of extremes, for example an increase in flood producing rainfall is likely to affect the capacity and maintenance of storm water, drainage and sewerage infrastructure (Douglas, 2008). In many parts of the world including Central Asia and parts of Europe aging infrastructure, high operating costs, low responsiveness to customers and poor access to capital markets means poor sewerage systems (Evans and Webster, 2008). Most urban centers in sub-Saharan Africa and in Asia have no sewers (Hardoy, Mitlin and Satterthwaite, 2001). Current problems of pollution and flooding will be exacerbated by an increase in climatic extremes.

Major settlements contain extensive infrastructure and are dependent on lengthy infrastructure networks for water, power, telecommunications, and transport, in particular for trade. Aspects of these networks in particular trade and transport are likely to be exposed to a wide range of extreme events as they likely extend far from the settlement in question. Modern logistics systems are intended to minimise slack and redundancies and as a result are particularly vulnerable to disruption by extreme events (Love, Soars and Puempel 2010). In early 2000, the Bruce highway in Tulley, Australia was flooded with major consequences to the transport system. In total 290 vehicles (150 cars and 140 trucks) were delayed at an estimated cost of AU$638,000.

Electricity transmission infrastructure is highly vulnerable to extreme storm events, particularly wind and lightning, and in some cases heat waves (EA, 2007 Science Report – SC20061/SR6). In France, the passage of Lothar and Martin storm across France caused the greatest devastation to an electricity supply network ever seen in a developed country (Abraham et al., 2000). According to a report by Abraham et al. (2000), citing sources of Electricité de France, 120 high-voltage transmission pylons were toppled, 36 high-tension transmission lines, a quarter of the total lines in France, were lost. The increase in storm activity could potentially generate significant increases in the cost of power supply and infrastructure maintenance from increased frequency and length of power blackouts and disruption of services. Droughts may also affect the supply of cooling water to power plants, disrupting the ongoing supply of power (Rubbelke and Vogele, 2011).

Transport infrastructure is highly vulnerable to extreme rainfall events leading to flood damage to road, rail, bridge, airport, port and especially tunnels (Love, et al., 2010). Increased temperatures and solar radiation could reduce life of asphalt on road surfaces (Meizhu, et al., 2010). Extreme temperature may cause expansion and increased movement of concrete joints, protective cladding, coatings and sealants on bridges and airport infrastructure, and stresses the steel in bridges and disrupts rail travel.

Damage to buildings and urban facilities result from the increased frequency and intensity of extreme rainfall, wind and lightning events. Buildings and facilities close to the coast are particularly at risk when storm surges are combined with sea level rise. In commercial buildings, vulnerable elements are lightweight roofs commonly used for warehouses, causing water spoilage to stored goods and equipment. During the Lothar and Martin storms, the most vulnerable public facilities were schools, particularly those built in the 1960s/70s and during the 1990s with the use of lightweight architectural elements of metal, plastic, and glass in walls and roofs (Abraham et al., 2000).

4.4.5.3. Tourism

The tourism sector is highly sensitive to climate, since climate is the principal driver of global seasonality in tourism demand (Lise and Tol, 2002; Becken and Hay, 2007.). 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). It is 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).

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 reduction of 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. Salinization of the groundwater resources due to SLR, 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. 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). Capacity to recover is likely to depend on the degree of dependence on tourism with diversified economies being more robust (Ehmer and Heymann, 2008). However, 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 and energy consumption (Elsasser and Bürki, 2002).

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 4-12). 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 (Source: Scott et al., 2008)]

A number of potential of climate extreme impacts on tourism regions and activities can be pointed out.

Tropics: Global tropical cyclone intensity is projected to increase during the 21st century between 3 and 11% under conditions roughly equivalent to A1B emissions scenarios (Chapter 3 SREX report). In the Caribbean, tourist activities are reduced as beaches erode with sea level rise, and coral is bleached, impacting snorkelers and divers (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 For example, Ross River fever outbreaks in Cairns, Australia, have a significant impact on the local tourist industry (Tong and Hu, 2001).

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 (Becken and Hay, 2007. 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 (snow for 100 days a season) by approximately 2030, as opposed to 85% today (Elsasser and Bürki, 2002). In Austria , 83 percent of ski resorts are currently snow-reliable but an increase in temperature of one and two degree Celsius will reduce this number to 67% and 50% respectively (Abegg et al., 2007).. In Austria, ski season simulations shows that snowmaking technology can maintain snow reliable conditions until until the 2040s (A1B) to the 2050s (B1), but by the end of the century the required production in snow volume is projected to increase by up to 330% (Steiger, 2010).

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 4-12 HERE:
Table 4-12: Identification of extreme impacts affecting the tourism sector by regions. Sources: IPCC 2007; Ehmer and Heymann, 2008; Scott et al., 2008]

4.4.6. Human Health, Well-Being, and Security

IPCC AR4 reported that malnutrition and diarrheal diseases are the two leading cause of climate change related health problems, although published reports from developing countries are limited. This finding is important, because these two leading problems are closely related to extreme events as described below.

Research conducted includes those of heat wave, flood, drought, cyclone, and combination of the above. These extreme weather events can occur even if climate change did not occur. However, the frequency and severity of heatwaves, floods, droughts and the magnitude in cyclones increases as global warming occurs (see Chapter 3).

Heat waves have affected developed countries, as exemplified by the 2003 European heat wave. Heat extremes can claim casualties even in tropical countries; Hajat et al. (2005) reported that heat extremes affected Delhi, India. He also demonstrated that the mortality pattern due to heat in Delhi was different from that of developed countries; In Delhi, the heat effect lasted longer than that in London, England, for example. In this regard, more research on heat waves should be conducted in developing countries in order for the adaption plans to be based on each local condition.

Floods directly cause deaths, injuries, followed by infectious diseases (such as diarrhea) and malnutrition due to crop damage, as with heat waves (see section 4.4.4). In Dhaka, Bangladesh, the severe flood in 1998 caused diarrhea during and after the flood, and the risk of non-cholera diarrhea was higher among those from a lower socio-economic group and not using tap water (Hashizume M et al., 2008). In 2002 report, WHO assumed that climate change would not cause diarrhea in 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). In some cases, 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 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).

Studies indicate that there is a strong climate signal in forest fires throughout the American West and Canada and that there is a projected increase in severe wildfires in many areas (Gillett, Weaver et al. 2004; Westerling, Hidalgo et al. 2006; Westerling and Bryant 2008). The direct effects of these fires on human health are burns and smoke inhalation but ecosystem degradation by loss of vegetation on slopes leading to increase soil erosion and increased risk of landslides will further increase indirect health impacts (McMichael, 2008; Campbell-Lendrum et al., 2007).

Evaluation of how impacts of extreme climate effect human health tend to focus on the direct, immediate effects of the event, using parameters that are often easier to obtain and quantify like death statistics or hospitalizations. These direct observable outcomes are used to demonstrate the extremity of an event and as a comparison metric to measure against other extreme events. What are not often reported, because they are one step removed from the event, are the indirect health impacts. Because indirect impacts are hard to monitor and are often temporally separated from the event, they are effectively removed from the cause-and-effect linkage to that event. Examples of indirect health impacts from extreme weather events include illnesses or injury resulting from disruption of human infrastructure built to deal with basic needs like medical services; exposure to infectious or toxic agents after an extreme event like cyclones or flooding (Schmid, Lederer et al. 2005); stress, anxiety and mental illness after evacuation or geographical displacement (Fritze, Blashki et al. 2008) as well as increased susceptibility to infection (Yee, Palacio et al. 2007); disruption of socio-economic structures and food production that lead to increases of malnutrition that might not manifest until months after an extreme event (Haines, Kovats et al. 2006; McMichael, Woodruff et al. 2006). Indirect health impacts are therefore a potentially large but under-examined outcome of extreme weather events that lead to a substantial underestimation of the total health burden.

There is a growing body of evidence that mental health impact from extreme events is substantial (Neria, Nandi et al. 2007; Berry, Bowen et al. 2010). Often overshadowed by the physical health outcomes of an event, the psychological effects tend to be much longer lasting and can affect a larger portion of the population than the physical effects (Morrissey and Reser 2007). An extreme event may affect mental health directly from acute traumatic stress to an event with common outcomes of anxiety and depression. It can also have indirect impacts during the recovery period associated with the stress and challenges of loss, disruption and displacement. Furthermore, indirect mental health impacts could even affect individuals not directly associated with an event like grieving friends and family of those who die from an event or the rescue and aid workers who suffer post-traumatic stress syndrome (PTSD) after their aid efforts. Long term mental health impacts are not often adequately monitored but the body of research conducted after natural disasters in the past three decades suggests that the burden of PTSD among persons exposed to disasters is substantial (Neria, Nandi et al. 2007). A range of other stress-related problems such as complicated grief, depression, anxiety disorders, somatoform disorders and drug and alcohol abuse (Fritze, Blashki et al. 2008) have lasting effects, long after the causative event.

Although the above mentioned impacts were identified, we still have large limitations in evaluating health impact of climate change. 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.

4.5. Regionally Based Aspects of Vulnerability, Exposures, and Impacts

4.5.1. Introduction and Overview

The regional sections presented below are about extreme impacts related to weather and climate within the context of other issues and trends. Regional perspective, in social and economic dimensions, is very important since the policy interventions have a strong regional context.

In dealing with extreme climate events and impacts the following are considered; 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 strong interest in the observed and projected trends in climatic events, exposure, vulnerability, impacts and the role of climate change in explaining detected trends.

Each region has its own priorities and they influence the structure of the individual sections.

4.5.2. Africa

Introduction

Climate extremes exert 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. The frequency and intensity of extreme events, such as floods and droughts, has increased in Africa over the past few years (IPCC, 2007; Scholes and Biggs 2004), causing major human and environmental impact and disruptions to the economies of African countries, thus exacerbating vulnerability (Washington et al. 2004; AMCEN/UNEP 2002). The expected warming trend (see Christensen et al., 2007) is likely to produce extreme impacts (Boko et al., 2007) including: 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). However, there is still limited information available on observed frequency and projections of extreme events (Christensen et al., 2007, and Chapter 3.2.3 of SREX report), despite frequent reporting of such events, including their impacts.

Agriculture is the economic sector that is most vulnerable and most exposed to natural hazards in Africa. It 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 and rainfall, drought and weather extremes is making Sub-Saharan Africa extremely vulnerable. This vulnerability is exacerbated by poor health, education and governance standards (Brooks et al., 2005).

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 to 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 by 2050 (Reid et al., 2007).

[INSERT FIGURE 4-13 HERE:
Figure 4-13: People Affected by Natural Hazards from 1971-2001.]
[Updated figure on climatic distasters needed]

Droughts and heat waves

The number of warm spells has increased in Southern and Western Africa over the last decades, together with a decrease in the number of extremely cold days (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 multi-year drought periods is severe famine, such as the one associated with the drought in the Sahel in 1980s, causing many casualties and important socio-economic losses (see case study 9.3, "Drought and Famine in Ethiopia in the Years 1999-2000"). 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 (e.g. famine, death of cattle, soil salinisation), and indirect (e.g. illnesses such as cholera and malaria) (Few et al., 2004).

The water sector is strongly influenced by, and sensitive to, periods of prolonged drought conditions in a continent with limited water storage infrastructures. Natural water reservoirs such as lakes experience a marked interannual water level fluctuation related to rainfall interannual variability (Nicholson et al., 2000, Verchusen et al., 2000). Since the early 1980's there is a decreasing trend in the water lake levels (e.g., in lakes Tanganyika, Victoria and Turkana), with a major decrease during the early 1990's, followed by a minor recovery between 1998-2004 (Swenson and Wahr, 2009). This is particularly evident in 2004/2005, when large water bodies such as Lake Victoria, recorded the lowest water levels since the beginning of the century old instrumental register.

Large changes in hydrology and water resources linked to climate variability have led to water stress conditions in human and ecological systems in Southern Africa (Schulze et al., 2001; New, 2002), south-central Ethiopia (Legesse et al., 2003), Kenya, Tanzania (Eriksen et al., 2005) and more generally, 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 (drought sensitive population), 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 and negatively impacts on vulnerability. 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). As water demand increases, the population exposed to different drought conditions (agricultural, climate, urban) is expected to increase as well.

One third of Africans now live in drought-prone areas, mainly in the Sahel, around the Horn of Africa and in southern Africa. Increasing drought risk will 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 2003-2004 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 & Lambi, 2006).

Extreme rainfall events and floods

Recent studies on observed rainfall trends are not conclusive about changes in extreme precipitation (Trenberth et al., 2007, reported in Chapter 3). Some regional investigations observed an increase in heavy rainfall events in southern Africa (Usman and Reason, 2004), including evidence for changes in seasonality, inter-annual variability and weather extremes (Richard et al., 2001, Tadross et al., 2005a). It is known that heavy precipitation is likely to induce landslides and debris flows in tropical mountain regions (Thomas and Thorp, 2003) with potential extreme impacts on human settlements. Increase in temperatures together with increased inter-annual variability of rainfall in the post-1970 period (e.g. southern Africa and Sahel,) have led to higher rainfall anomalies and more intense and widespread droughts (Richard et al., 2001; Fauchereau et al., 2003). In the arid and semi-arid areas of countries of the Horn of Africa, extreme rainfall events are often associated with a higher risk of the vector and epidemic diseases of 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 phase of ENSO events (e.g. 1982-83, 1997-98, 2006-07). When such events occur, important economic and human losses result. In 2000, floods in Mozambique (Case Study 9.5), particularly along the valleys of the rivers Limpopo, Save and Zambezi, 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 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).

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).

In 1975-2007, the estimated average annual economic loss caused by tropical cyclones and floods accounted for 0.55% and 0.19% of GDP, respectively, in affected countries of Sub-Saharan Africa. This indicates a higher exposure under an increasing occurrence of disasters (UNISDR, 2009b).

Dust storms

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 over 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, health and structures. They erode fertile soil, uproot young plants, bury water canals, homes and properties, and cause respiratory problems (Case Study 9.4, "Sand and Dust Storms"). Meningitis transmission, associated with dust in semi-arid conditions and overcrowded living conditions, could increase with climate change as arid and dusty conditions spread across the Sahelian belt of Africa (DFID, 2004).

Adaptation
According to Parry et al. (2007), there exist strategies to adapt to drought conditions, such as the use of emergency animal feed, culling of weak livestock for food, and using multiple species of animals more adaptable to climate extremes. During drought periods, pastoralists and agro-pastoralists change from cattle to sheep and goats, as the feed requirements of the latter are lower and they tolerate higher temperatures (Seo and Mendelsohn, 2006b).As the pastoralists in Africa move from the dry northern areas to the wetter southern areas of the Sahel, their nomadic mobility reduces the pressure on low-capacity grazing areas as they are not grazed consistently (Boko et al., 2007). However, consecutive dry years with widespread disruption reduce society's coping capacity by providing less recovery and preparation time between drought events (Adger, 2002).

4.5.3. Asia

Asia includes mega-deltas which were identified to be among the most vulnerable regions by IPCC (2007). Mega-deltas are highly susceptible extreme impacts due to a combination of the following factors; high hazard rivers, coastal flooding, and increased population exposure from expanding urban areas with large proportions of high vulnerability groups (Nicholls et al., 2007). Asia is also at threat because of the changes in frequency and magnitude of extreme events and severe climate anomalies, such as heatwaves, intense rain, floods, droughts and tropical cyclones (Cruz et al., 2007). The changes will affect not only natural and physical systems but also human systems.

Tropical cyclones (typhoons or hurricanes)
Tropical cyclone mortality risk is highly geographically concentrated in Asia, and takes both a relative and absolute high exposure to population and GDP.

Amplification in storm-surge heights and an enhanced risk of coastal disasters along the coastal regions of East, South and South-East Asian countries is likely as a result of climate change (Cruz et al., 2007). This may be the result from an increase in sea-surface temperatures, lower pressures and stronger winds associated with tropical storms (Kelly and Adger, 2000).

Damage due to coastal flooding is sensitive to the change in magnitude of tropical cyclones. For example, changes in coastal flooding and associated damage were projected for the inner parts of three major bays (Tokyo Bay, Ise Bay, and Osaka Bay) in Japan (Suzuki, 2009). The projections were based on calculations of inundations for different sea levels and different strengths of typhoons, using a spatial model with information on topography and levees. The research revealed that a typhoon which is 1.3 times as strong as the design standard with a sea level rise of 60cm would cause damage costs of 298, 4001, 2687 (billion JPY) in the investigated bays respectively

Location can also be a major factor in the outcomes from tropical cyclones. For example two cyclones in Indian Ocean (Sidr and Nargis) of similar magnitude and strength caused a significantly different number of fatalities. A comparison is presented in 9.3.1 as a case study.

Paddy rice in Japan is most vulnerable to cyclone damage for several days around the rice heading day (Masutomi et al., 2010). To alleviate typhoon damage adjustment of heading stage can be altered by changing the planting date. However, if the intensity or landfall season changes in future, the area damaged by the typhoon will alter.

Awareness, improved governance and development are essential in coping with extreme tropical cyclone and typhoon events in developing Asian countries (Cruz et al., 2007). This could partly explain why typhoon losses in China since 1983 were negligible 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).

Flooding

The geographical distribution of flood risk is heavily concentrated to India, Bangladesh and China, causing high human and material losses (Brouwer et al. 2007; Shen et al., 2007; Dash et al., 2007). In South Asian countries, flooding has contributed 49% to the modelled annual economic loss of GDP since the 1970s (UNISDR, 2009b). However, 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 population change.

In July 2005, severe flooding occurred in Mumbai, India. 944 millimetres of rain fell in a 24-hour period, nearly half of the average yearly rainfall of 2147 centimetres (Kshirsagar, 2006). The consequent flooding affected many households, including those in the more affluent parts of the city. Most metropolitan cities in India, including Mumbai, have poor urban drainage systems, which are easily blocked and are vulnerable even to short spells of rain. Ranger et al. (2010) analysed risk from heavy rainfall in the city of Mumbai, concluding that that total losses (direct plus indirect) associated with a 1-in-100 year event could treble in the 2070s compared with current situation ($690 – $1890 million USD, including $100-$400 million USD of indirect losses), and that adaptation could significantly reduce future damages.

As noted in the final report for the Ministry of Environment and Forest from the Government of the People's Republic of Bangladesh, (NAPA, 2005), flooding in Bangladesh is a normal, frequently recurrent, phenomenon. Four types of floods 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, river spills and drainage congestions cause inundation of 20 to 25% of the country area. Inundation areas for 10-, 50- and 100-year floods, constitute 37%, 52% and 60% of the country area respectively. Moderate and high flood prone cropland areas inundate 1.32 and 5.05 million ha of land, respectively. 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 km^2 (10 million ha), rendered 30 million people homeless, and caused heavy losses to infrastructure (including damage to 500,000 homes).

Annual events of peak lake stage and of severe floods have increased dramatically during the past few decades in the 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). 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.

Different flooding trends have been detected and projected in various regions. There are significant upward trends in annual flood maxima of the lower Yangtze river in summer (flood season) (Jiang et al., 2008). There is an increasing likelihood of extreme floods during the period 2050 to 2100 for the Mekong River (Delgado et al., 2009). Both upward and downward trends were detected over the last four decades in four selected river basins of the north-western Himalaya (Bhutiyani et al., 2008). Hirabayashi et al., (2008b) show it is *very likely* that there will be an increase in the risk of floods in most humid Asian monsoon regions.

Heavy rainfall and flooding is also an important issue for environmental health in urban areas, as surface water is quickly contaminated during heavy rainfall events. Urban poor populations often experience increased rates of infectious disease after flood events. Increases in cholera, cryptosporidiosis and typhoid fever have been reported in low- and middle-income countries (Kovats and Akhtar, 2008).

Temperature extremes

Global warming is accompanied by an increase in the frequency and intensity of heat waves and by milder cold seasons. Significant increase of heat wave duration and severity has been observed in many countries of Asia, including Asian Russia, Mongolia, China, Japan and India (Cruz et al., 2007). Weakening cold extremes (cold waves) were noted in Mongolia and Japan.

Extremely hot weather can affect both human and natural systems. In 2002, a heat wave was reported to have killed 622 people in the southern Indian state of Andhra Pradesh. Persons living in informal settlements and structures may be more exposed to high temperatures (Kovats and Akhtar, 2008).

Agriculture is also affected directly by temperature extremes. For example, rice, the staple food in many parts of Asia, is adversely affected by extremely high temperature, especially prior to or during critical pollination phases (see Section 4.4.4).

Droughts

Asia has a long history of drought, which has been linked with other extreme weather events. Increasing frequency and intensity of droughts has been observed in many parts of Asia, adversely affecting the socioeconomic, agricultural, and environmental conditions. Drought causes water shortages, crop failures, mass starvation, and wildfire. For example in Mongolia, from 1999 to 2002, a drought affected 70% of grassland, resulting in the death of 12 million head of livestock.

Increased droughts are attributed largely to a rise in temperature, particularly during the summer, drier months and during ENSO events (Cruz et al., 2007).

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).

During drought, severe water-scarcity results from one of, or a combination of the following mechanisms: insufficient precipitation, high evapotranspiration, and over-exploitation of water resources (Bhuiyan et al., 2006).

About 15% (23 million ha) of Asian rice areas experience frequent yield loss due to drought (Widawsky and O'Toole, 1990). The problem is particularly severe in Eastern India, where the area of drought-prone fields exceeds more than 10 million ha (Pandey et al., 2000). Even when the total rainfall is adequate, shortages at critical periods reduce yield (Kumar et al., 2007). Lowland rice production in the Mekong region is generally reduced because crops are cultivated under rain fed conditions, rather than irrigated, 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).

In the spring of 2010 severe droughts impacted some East and Southeast Asian countries, causing damages to crops, a drop in river levels and reservoirs, and economic losses. According to China's State Commission of Disaster Relief, 51 million Chinese were affected by the drought, with estimated direct economic losses at US$2.8 billion. In the Phillipines, according to the Philippine Department of Agriculture's Central Action Center (DACAC), the total damages caused by the drought reached US$244.4 million, with the loss in paddy rice production nearing 300,000 metric tons (Xinua, 2010).

Asian wetlands provide resources to people in inundation areas, who are susceptible to droughts. For achieving the benefits from fertilization for inundation agriculture in Cambodia, wide areas along the rivers need to be flooded (Kazama et al., 2009). Flood protection in this area needs to consider this benefit of inundation.

Wildfires

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 north-western and north-eastern China face more challenges for reduction 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 disasters from twelve Northern provinces of China between 1991 and 2006, grassland fire disasters have increased gradually with economic development and population growth, with significant impacts on the national stockbreeding economy (Liu et al., 2006).

Regional costs for the Asian region
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, the have been more than 1 million fatalities in Asia due to natural catastrophes, more than in all other continents combined (Spranger, 2008).

Focusing on 136 large port cities around the world, that have more than one million inhabitants, OECD (2008) investigated the exposure of economic assets and population to coastal flooding. Asia was found to have both a high number of cities (38%) and high exposure per city of population and assets when compared to other continents. Seventeen of the most populous cities among the global twenty are in Asia, and these are projected to experience a more than a 200 per cent increase in exposure to flooding by 2015, compared to 2005. It is also estimated that, by 2015, loss of life 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.

Accounting for cultural, political and historical factors, a degree of 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 the 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 the economic impacts of disasters (Adger, 1999; OECD, 2008).

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 from extreme events are likely to be exacerbated by rapid urbanisation; it is argued that health related risks could potentially worsen in Asian countries (Wu et al., 2010).

4.5.4. Europe

Introduction
Europe has higher population density and lower birth rate than any other continent. Europe currently has an ageing population. Life expectancy is high and increasing and child mortality is low and decreasing (Eurostat, 2010). European exposure to natural hazards has increased whereas vulnerability has decreased as a result of implementation of policy, regulations, risk prevention and management (EEA, 2008; UNISDR, 2009b). Temporal and spatial changes on extreme events involve losses and gains on natural resource and economic sectors basis over Europe.

Heat waves
Summer heat waves have become increasingly frequent in summer in most of Europe (Della-Marta et al., 2007; see Section 3.3.1) and have affected vulnerable segments of European society. During the 2003 heat wave, several tens of thousands of additional heat-related deaths were recorded (see chapter 9.3.1, case study 9.2). Urban heat islands pose an additional risk to urban inhabitants. Those most affected are the elderly, ill, and socially isolated (Wilby, 2003; see chapter 9.3.1, case study 9.2). There are mounting concerns about increasing heat intensity in major European cities (e.g. London and Wilby, 2003a). This is because of the vast population that inhabit urban areas, as 25% of Europeans live in areas exceeding 750,000 inhabitants (UN, 2004). Building characteristics, emissions of antropogenic heat from air conditioning units and vehicles, as well as lack of green open areas in some parts of the cities, may exacerbate heat feeling during heatwaves (e.g.Wilby, 2007, Stedman, 2004).

Droughts and wildfires
Drought risk is a function of the frequency, severity, spatial and temporal extent of dry spell, the vulnerability and exposure of population and its economic activity (Lehner, et al., 2006). In Mediterranean countries, drought hazard impact to a large sector of population historically produces economic damages larger than floods or earthquakes (e.g. the drought in Spain in 1990 affected 6 million people and caused material losses of 4.5 billion dollars, after EM-DAT, 2010). The most severe human consequences of droughts are often found in semiarid regions where water availability is already low under normal conditions, water demand is close to, or exceeds, natural availability and/or

society seldom lacks the capacity to mitigate or adapt to drought (Iglesias et al., 2009). Direct drought impacts affect all forms of water supply (municipal, industrial and agricultural). Other sectors and systems affected by drought occurrence are hydropower generation, tourism, forestry, and terrestrial and aquatic ecosystems.

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), central (Goldammer et al., 2005), Eastern (Kellomäki et al., 2005) and Northern Europe (Moriondo et al., 2006). In the Mediterranean it may lead to increased dominance of shrubs over trees (Mouillot et al., 2002), however, it does not translate directly into increased fire occurrence or changes in vegetation (Thonicke and Cramer, 2006).

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; SREX Report, chapter 3), whereas long-term processes are linked to global mean sea-level rise (Woodworth et al., 2005). Expected sea-level rise is projected to have impacts on Europe's coastal areas including land loss, groundwater and soil salinisation and damage to property and infrastructures (Devoy, 2008).

Hinkel et al. (2010) found that the total monetary damage in coastal areas of the Member Countries of the European Union (EU) caused by flooding, salinity intrusion, land erosion and migration is projected to rise strongly. The Netherlands is an example of a country that is highly susceptible to both sea-level rise and coastal flooding. Adaptation can reduce the number of people flooded by two orders of magnitude and the total damage costs by the factors of four to five (Hinkel et al., 2010).

Gale winds
Windstorms are most destructive climatic extremes in Europe. Severe windstorms are associated with westerly flow occurring mainly during moderately positive NAO phases (Donat et al., 2009). The most frequent track runs along the north coasts of the British Isles into 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, communication lines, damage to vulnerable elements of buildings (e.g. lightweight roofs) and by trees falling on houses. There is a lack of consensus on projected wind speed changes over Europe (Barthod, 2003; Nilsson et al., 2004; Schumacher and Bugmann, 2006).

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.

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 forests 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).

Flooding
Flooding is the most frequent and widely distributed natural risk in Europe. Economic losses from flood hazards in Europe have increased considerably over previous decades (Lugeri et al., 2010) and increasing exposure of people and economic assets is very likely to be the major cause of the long-term changes in economic disaster losses (Barredo, 2009). Exposure includes socio-economic development, urbanization and infrastructure construction on traditional flood-prone areas. Very high flood impacts were due to a few individual flood events (e.g. 1997 floods in Poland and Czech Republic, 2002 floods in much of Europe, and 2007 summer floods in UK). The increase of

frequency of short-duration precipitation in large parts of Europe is likely to increase the probability of flash floods (Dankers and Feyen, 2008) which are the most harmful in terms of human impacts (EEA, 2004b). Flash floods from extreme precipitation are enhanced for urbanized areas, catchments modified by changes in land use and vegetation cover (Robinson et al., 2003; Benito et al., 2010), and 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 and 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, linear infrastructures, such as roads, railroads, and underground rails with inadequate drainage will likely suffer flood damage (Defra, 2004a; Mayor of London, 2005). Increased runoff volumes may increase risk of dam failure (tailings dams and water reservoirs) with high environmental and socio-economic damages as evidenced by historical records (Rico et al., 2008).

In glaciated areas of Europe glacial lake outburst floods (GLOFs), although infrequent, have potential to produce immense socio-economic and environmental impacts. Glacial lakes dammed by young, unstable and unconsolidated moraines, and lakes in contact to the active ice body of a glacier increase the potential of a GLOF event occurring (e.g. Huggel et al., 2004). 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 the frequency of landslides (Schmidt and Dehn, 2000), which can impact on settlements and linear infrastructure. Observed trends in landslide occurrence point 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 groundwater flow and 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. Due to an increased use of mountainous areas for recreation and tourism there is increased exposure for the population leading to an increased rate of mortality due to snow avalanches. During the period 1985–2005, avalanche fatalities have averaged 25 per year in Switzerland (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 impacts on humans (loss of life and infrastructure) although in mountain forests avalanches may favour biodiversity (Bebi et al., 2009).

Europe is the leading region for the 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 per year, and with a 50% increase in precipitation by 30 days/yr.

Coping with extremes

Adaptation potential of European countries is relatively high, because of high gross domestic product and stable growth, educated and stable population (with the possibility of moving around the EU) and well developed political, institutional, and technological support systems (Kundzewicz and Parry, 2001). Adaptation to weather extremes allows for a reduction of exposure, adverse impacts, and vulnerability. A special European Union (EU) Solidarity Fund (Hochrainer et al., 2010) has been established to assist recovery after major natural hazards, and national and

EU adaptation programmes are being implemented (CEC, 2009). However, some groups of people – economically disadvantaged, elderly, sick or living alone are particularly vulnerable. The natural ecosystems in Europe that are most vulnerable to climate extremes are located in the Arctic, in mountain regions, in coastal zones (especially the Baltic wetlands) and in various parts of the Mediterranean. Mediterranean ecosystems are already affected by ongoing warming and decreasing precipitation (Alcamo et al., 2007), as well as high levels of human use and human stress.

Much work is being done in Europe to improve flood preparedness and management, including the 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, in some countries the design floods are adjusted using a "climate change safety factor" approach (Kundzewicz et al., 2010a, b). Water scarcity and droughts in the context of climate change was addressed by the European Union (COM/2007/0414 final) conveying a set of policy options, including water pricing, improving drought risk management, considering additional water supply infrastructures, fostering water efficient technologies and practices, and increasing a water-saving culture in Europe.

Promising adaptation options of forests to gale winds in Europe were found (Schelhaas et al., 2009) to limit the increase in exposure and vulnerability. This can be done by increasing the harvest levels that curb the current build-up of growing stock and reduction of the share of old and vulnerable stands. Adaptation strategies for buildings and infrastructures to the local conditions of extreme wind speeds could also lead to a significant reduction of storm loss potential under modified climate (Pinto et al., 2007).

[INSERT TABLE 4-13 HERE
Table 4-13: Summary of climate extremes in Europe – hazard, exposure, vulnerability, and impacts]

Costs for the European region

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). 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). 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.

4.5.5. Central and South America

Extremely warm temperatures in the Andes

Warming over the Andes includes increasing night time temperature minimum and day time maximum (Ruiz et al., 2011, Lozano et al., 2010). As a result, glaciers, mountain moorlands *(páramos*, neo-tropical high elevation wetlands*)* and cloud forests in the Andes are experiencing abrupt climate change (Ruiz et al., 2008; Vergara et al., 2010). Field measurements (Ruiz et al., 2011) and analyses of ensemble products from global circulation models (Bradley et al., 2006) indicate that the rate of warming may be much faster at higher altitudes in the Andes. There is also a well-documented major loss in ice cover and substantial evidence that the associated glacier retreat is accelerating. Tropical glaciers in the Andes (those located between Bolivia and Venezuela) covered an area of over 2,940 km^2 in 1970 but declined to 2,758 km^2 in 1991 (INRENA, 2006) and to 2,493 km^2 by 2002 (Kaser, 2005). In Peru alone, glaciers covered an area of 2,041 km^2 in 1970 but had declined nearly 22% to 1,595 km^2 by 1997 (INRENA, 2006). The largest of these glaciers in the Cordillera Blanca have lost 15% of their glacier surface area in a period of 30 years. Many of the smaller glaciers in the Andes have already been heavily affected and others are likely to completely disappear within a generation. Glacier retreat diminishes the mountains' water regulation capacity, making it more expensive to supply water for human consumption, power generation, or agriculture, as well as for ecosystem integrity in associated basins. Impacts on economic activities have been monetized (Vergara et al., 2009) and found to represent billions of dollars in losses to the power and water supply sectors. However, the loss of integrity of high-mountain habitats is more difficult to evaluate.

Data recently made available (Ruíz et al., 2011) suggests that climate impacts have already altered the circulation patterns responsible for producing and moving water vapor to the region. These changes have probably contributed to the disappearance of high-altitude water bodies as well as to the increased occurrence of natural and human-induced mountain fires (a record setting season of high altitude fires was registered in the Northern Andes in early 2008). It could also be behind some of the reductions in populations of mountain flora and fauna in the Andes. Changes in the altitudinal location of dew points, a consequence of warming of the troposphere, is also thought of being capable to affect the relative formation of clouds and horizontal precipitation and eventually lead to disruption of cloud forests, and local weather patterns. Rapid warming may also lead to an increase in the rate of desertification of mountain habitats. Combined, these impacts may constitute a serious threat to water supply in the region (Vergara et al., 2010).

Changes in the stability and functioning of the Amazon basin

The Amazon basin is a key component of the global carbon cycle. Annually, these tropical forests process approximately 18 Pg C through respiration and photosynthesis. This is more than twice the rate of global anthropogenic fossil fuel emissions (Dirzo and Raven, 2003). The basin is also the largest global repository of biodiversity and produces about 20% of the world's flow of fresh water into the oceans. Despite the large CO_2 efflux from recent deforestation, the Amazon rainforest ecosystem is still considered to be a net carbon sink of 0.8–1.1 Pg C per year because growth on average exceeds mortality (Phillips et al., 2008).

However, current climate trends and human-induced deforestation may be transforming forest structure and behavior (Phillips et al., 2009). Increasing temperatures may accelerate respiration rates and thus carbon emissions from soils (Malhi and Grace, 2000). High probabilities for modification in rainfall patterns (Malhi et al., 2008) and prolonged drought stress may lead to reductions in biomass density. Resulting changes in evapotranspiration and therefore convective precipitation could further accelerate drought conditions and destabilize the tropical ecosystem as a whole, causing a reduction in its biomass carrying capacity or dieback. In turn, changes in the structure of the Amazon and its associated water cycle would have implications for the many endemic species it contains and result in changes at a continental scale.

A recent World Bank report assessed the risk of Amazon dieback – extreme impact induced by climate change (Vergara and Scholz, 2010). The study concludes that in the absence of CO_2 fertilization, the probability of Amazon dieback under scenario A1B is highest in the Eastern Amazon (61% probability of it taking place this century) and lowest in the Northwest (0%), but that its severity increases over time and also is a function of the emission trajectory considered. These results also indicate the need to avoid reaching a point that would result in a climate-induced loss of Amazon forests. The study recommends that Amazon dieback be considered a threshold for dangerous climate change. Likewise, the estimated combined effects of climate impacts and deforestation on the integrity of the Amazon strongly suggests that deforestation should be rapidly reduced.

In fact, in the short span of five 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), to be followed by another record drought in 2010. The 2005 drought was atypical because it affected mostly the western and southwestern Amazon basin, as opposed to the more typical El Niño-related droughts which affect central, northern and eastern Amazon basin, such as the severe drought in northern Amazon basin in early 2010 (Climanalise, 2010). By and large, droughts in the Amazon basin 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).

Long-term rainfall-exclusion experiments for central (Nepstad et al., 2007 and Brando et al., 2008) and northeastern Amazon basin (Fischer et al., 2007) showed large tree mortality.

Extreme rainfalls in South America

Extreme rainfall episodes have caused natural disasters of great proportion in parts of South 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. Also, an unusually heavy rainy season blamed on La Niña has overwhelmed levee systems flooding farmland and cities in Colombia in 2010, forcing authorities to declare a national disaster. Projections of rainfall extremes for the future, although highly uncertain at present, point out for more intense rainfall episodes due to global warming and longer drought periods for most of South America (Kitoh et al, 2010, 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 November-February 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).

Extreme sea surface temperatures along Central America and bleaching of the Mesoamerican Reef

Extreme high sea surface temperatures have been increasingly documented in the western Caribbean near the coast of Central America and have resulted in frequent bleaching events (1993, 1998, 2005, and again in 2010) of the Mesoamerican coral reef, located along the coasts of Belize, Honduras, Guatemala and Mexico. In 2005, regionally averaged temperatures were the warmest in the western Caribbean for more than 150 years (Easkin, 2010). These extreme temperatures caused the most severe coral bleaching ever recorded in the Caribbean: more than 80% of the corals surveyed were bleached, and at many sites more than 40% died. Recovery from such large scale coral mortality will depend on the extent to which coral reef health has been compromised and the frequency and severity of subsequent stresses to the system. More than one bleaching event over a short timeframe can be devastating (Christensen et al., 2007). An analysis (Vergara et al., 2009) indicates that were extreme sea surface temperatures to continue, it is possible that the Mesoamerican coral reef will collapse by mid-century, due to high sea surface temperature anomalies, causing billions of dollars in losses.

In the wake of coral collapse, major economic impacts on fisheries, tourism, and coastal protection are anticipated, as well as severe loss of biodiversity, species extinction and impacts on ecosystem integrity. Appropriate monetization of these impacts is not easy. Among these, the loss of species and ecosystem integrity is much more difficult to evaluate, yet may be most important. One-third of the more than 700 species of reef-building corals worldwide are already threatened with extinction (Carpenter et al., 2008). It is estimated that between 60 to 70 endemic species of corals in the Caribbean are also in danger. The cost of reducing vulnerability of corals to bleaching and accelerating recovery of affected populations are likely to be very high but they remain to be assessed.

Regional costs

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.

4.5.6. North America

Introduction

North America (Canada, Mexico and USA) is relatively well developed, although differentiation in living standards exists across and within countries. This differentiation in adaptive capacity, combined with a decentralized and essentially reactive response capability, underlies the region's vulnerability (Field et al., 2007). Furthermore, population trends within the region have increased vulnerability by heightening exposure of people and property in areas that are affected by extreme events. For example, population in coastline regions of the Gulf of Mexico region in the United States increased by 150% from 1960 to 2008, while total U.S. population increased 70% (U.S. Census Bureau, 2010).

Heat Waves

For North America, there has *likely* been an overall increase in unusually warm days and nights and an overall decrease in unusually cold days and nights (see Section 3.3.1.1, Table 3.2). For instance, by the 2000s, twice as many record high temperatures as record lows were set in the U.S. (Meehl et al., 2009). Since 1960, there has been an increase in heat waves in the United States although heat waves of the 1930s associated with extreme drought still dominate the twentieth-century time series (see Section 3.3.1.1, Table 3.2). By the end of the century, there will *very likely* be an overall increase in unusually warm days, unusually warm nights, and heat waves and an overall decrease in unusually cold days and nights for Canada, the United States, and northern Mexico (see Section 3.3.1.3, Table 3.3). As an example, by the middle of the century under a mid-range scenario of future greenhouse gas emissions, a hot day currently experienced, on average, once every 20 years is projected to occur every 3 years over portions of the continental United States and every 5 years over much of Canada. By the end of the century, this hot day would occur, on average, at least every other year (see Section 3.3.1.3).

Heat waves have impacts on many sectors, most notably on human health, agriculture, forestry and natural ecosystems, and energy infrastructure. One of the most significant concerns is human health, in particular, mortality and morbidity. In 2006 in California, at least 140 deaths and more than 1000 hospitalizations were recorded during a severe heat wave (CDHS, 2007; Knowlton et al., 2008). In 1995 in Chicago, more than 700 people died during a severe heat wave. Following that 1995 event, the city developed a series of response measures through an extreme heat program. In 1999, the city experienced another extreme heat event but far fewer lives were lost. While conditions in the 1999 event were somewhat less severe, the city's response measures were also credited with contributing to the lower mortality (Palecki et al., 2001).

While heat waves are projected to increase, their net effect on human health is uncertain, largely because of uncertainties about the structure of cities in the future, adaptation measures, and access to cooling (Ebi and Meehl, 2007). Many cities have installed heat watch warning systems.

Heat waves have other effects. There is increased likelihood of disruption of electricity supplies during heat waves (Wilbanks et al., 2008). Air quality can be reduced, particularly if stagnant high pressure systems increase in frequency and intensity (Wang and Angell, 1999). Additionally, extreme heat can reduce yield of grain crops such as corn and increase stress on livestock (Karl et al., 2009).

Drought and wildfire

There has been no overall change in drought for North America: there have been trends towards more severe drought conditions in some North American regions, such as southern and western Canada, Alaska, and Mexico, and towards decreases in droughts in some other regions (Table 3.2, Section 3.5.1.1; Kunkel et al., 2008). Increases in drought area are *likely* in the southwest United States and northwest Mexico (Table 3.3, see Section 3.5.1.3). Additionally, multi-year droughts are projected to be more frequent in the southwest United States.

Droughts are currently the third most costly category of natural disaster in the United States (Carter et al., 2008). The effects of drought include reduced water quantity and quality, lower streamflows, decreased crop production, ecosystem shifts and increased wildfire risk. The severity of impacts of drought is related to the exposure and vulnerability of affected regions.

From 2000 to 2007, excluding 2003, crop losses accounted for nearly all direct damages resulting from U.S. droughts (NOAA, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007). Similarly, drought has had regular recurring impacts on agricultural activities in Northern Mexico (Endfield and Tejedo, 2006). In addition to impacts on crops and pastures, droughts have been identified as causes of regional-scale ecosystem shifts throughout Southwestern North America (Allen and Breshears, 1998; Breshears et al., 2005; Rehfeldt et al., 2006).

While more difficult to quantify, drought also has multiple indirect impacts in North America. Droughts pose a risk to North American power supplies due to a reliance on sufficient water supplies and quality for hydropower generation and cooling of nuclear, coal and natural gas generation facilities (Wilbanks et al., 2008; Goldstein, 2003). Projections of water availability in heavily contested reservoir systems such as the Colorado River Basin indicate that climate change will likely reduce states' abilities to meet existing agreements (Christensen et al., 2004).

Additionally, droughts and dry conditions more generally have been linked to increases in wildfire activity in North America. Westerling et al. (2006) found that wildfire activity in the western United States increased substantially in the late 20th century and that the increase is caused by higher temperatures and earlier snowmelt. Similarly, increases in wildfire activity in Alaska from 1950 to 2003 have been linked to increased temperatures (Karl et al., 2009). Anthropogenic warming was identified as a contributor to increases in Canadian wildfires (Gillett et al., 2004).

In Canada, forest fires are responsible for one third of all particulate emissions, leading to heightened incidence of respiratory and cardiac illnesses as well as mortality (Rittmaster et al., 2006). Wildfires not only cause direct mortality, but the air pollution produces increases eye and respiratory illnesses (Ebi and Balbus, 2008). The principal economic costs of wildfires include timber losses, property destruction, fire suppression and reductions in tourism (Butry et al., 2001; Morton et al., 2003).

Inland flooding

There has been a *likely* increase in heavy precipitation in many areas of North America since 1950 (Table 3.2). Some of the largest increases in total and intense precipitation have been observed in the central plains and northwestern Midwest (see Section 3.3.2.1). The number and intensity of heavy precipitation days is *very likely* to increase over most regions of Canada and the United States, except the southwest United States, under mid- to high-range scenarios of future greenhouse gas emissions (Table 3.3). Since 1950, there have *likely* been earlier spring peak river flows in snow-dominated regions, a trend that is *likely* to continue through 2100 (Table 3.1, see Section 3.5.2.1).

Flooding and heavy precipitation events have a variety of significant direct and indirect human health impacts (Ebi and Balbus, 2008). Heavy precipitation events are strongly correlated with the outbreak of waterborne illnesses in the United States—51 percent of waterborne disease outbreaks were preceded by precipitation events in the top decile (Curriero et al., 2001). In addition, heavy precipitation events have been linked to North American outbreaks of vector-borne diseases such as Hantavirus and plague (Engelthaler et al., 1999; Hjelle and Glass, 2000; Parmenter et al., 1999).

In terms of property damages, flooding is the most costly category of natural disaster in Canada and the United States from 2000 to 2008 (NOAA, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008; Public Safety Canada, 2007). Beyond direct destruction of property, flooding has important negative impacts on a variety of economic sectors including transportation and agriculture. Heavy precipitation and field flooding in agricultural systems delays spring planting, increases soil compaction and causes crop losses through anoxia and root diseases and variation in precipitation is responsible for the majority of the crop losses (Mendelsohn, 2007). Heavy precipitation in the American Midwest in 1993 flooded 8.2 million acres of soybean and corn fields, decreasing corn yields by 50 percent in Iowa, Minnesota and Missouri, and 20-30 percent in Illinois, Indiana and Wisconsin (Changnon, 1996). Furthermore, flood impacts include temporary damage or permanent destruction of infrastructure in most modes of transportation (Zimmerman and Faris, 2010), For example, heavy precipitation events are the most costly weather condition facing U.S. rail transportation (Changnon, 2006).

Coastal storms and flooding

Since 1950, there has been a *likely* increase in extreme high water, related to trends in mean sea level and variations in regional climate (Table 3.1, see Section 3.5.3.1), and it is *very likely* that mean sea level rise will continue to contribute to increases in extreme sea levels, as projected through 2100 (Table 3.1). Sea level rise alone increases the destructive power of hurricanes because the level of storm surge will increase with sea level rise (see Section 3.4.4). For tropical cyclones, there has been no global trend in frequency since 1983, but an increasing global trend in intensity since 1983 (Table 3.1). For extratropical cyclones, there has been a *likely* poleward shift in storm tracks and a *more likely than not* intensification in high latitudes (Table 3.1). Through 2100, tropical cyclones are projected to *likely* decrease or remain unchanged in global frequency, with *likely* increases in mean maximum wind speed in some ocean basins and *likely* increases in tropical cyclone-related rainfall rates; extratropical cyclones will *likely* be reduced in mid-latitudes and *more likely than not* increase in number and intensity for high latitudes (Table 3.1).

North America is exposed to coastal storms, and in particular, hurricanes. 2005 was a particularly severe year with 14 hurricanes (out of 27 named storms) in the Atlantic (NOAA, 2005). There were more than 2000 deaths during 2005 (Karl et al., 2009) and widespread destruction on the Gulf Coast and in New Orleans in particular. Property damages exceeded $100 billion (Pielke et al., 2008; Beven et al., 2008). Hurricanes Katrina and Rita destroyed 100 oil and gas platforms in Gulf and damaged 558 pipelines, halted all oil and gas production in the Gulf, and disrupted 20% of US refining capacity (Karl et al., 2009). Although simulations indicate climate change will increase mean damages from North American hurricanes, 2005 may be an outlier for a variety of reasons – the year saw a higher than average frequency of storms, with greater than average intensity, making more frequent landfall, including in the most vulnerable region of the country (Nordhaus, 2006).

The major factor increasing the vulnerability of North America to hurricanes is the growth in population (see, for example, Pielke et al., 2008), and increase in property values, particularly along the Gulf and Atlantic coasts of the United States. While some of this increase in vulnerability has been offset by adaptation and improved building codes, the ratio of hurricane damages to national GDP has increased by 1.5 percent per year over the past half-century (Nordhaus, 2006).

Future sea level rise and increased storm surge are projected to substantially increase storm surge inundation and property damage in coastal areas. Hoffman et al. (2010) assumed no acceleration in the current rate of sea level rise through 2030 and found that property damage from hurricanes would increase by 20%. Frey et al. (2010) simulated the combined effects of sea level rise and more powerful hurricanes on storm surge in southern Texas in 2080. They found that the area inundated by storm surge could increase 60 to 230% in smaller hurricanes and 6 to 25% in very large (Category 5) hurricanes. Property damage is estimated to increase 400 to 700% in the smaller hurricane and 25 to 100% in the very large hurricane. No adaptation measures were assumed in either study.

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).

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., 2008).

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 in the US.

Interpretation of change

Smaller scale but more frequent storm events can together cause substantial losses. Changnon (2001) found increases in normalised losses from various thunderstorm 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).

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 and Cutter, 2008).

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). In New Zealand overall mean temperatures have risen marginally, however this does not correspond with an increase in number of hot days as it does in Australia. Instead, the numbers of cold nights that occur in New Zealand are decreasing, lifting the minimum temperature (Salinger and Griffiths, 2001).

The El Niño-Southern Oscillation (ENSO) is a strong regional driver of climate variability (see 5.3.5.4). 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 temperatures 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. Due to heat related stresses, the Queensland ambulance service recorded a 53% increase in ambulance call-outs (Steffen et al., 2006). A week long heat wave in Victoria in 2009 corresponded with a sharp increase of deaths in the state. For the week of the wave a total of 606 deaths were expected and there were a total of 980 deaths, representing a 62% increase (Department of Human Services, 2009).

An increase in heat-related deaths is projected in the warming region (Hennessy et al., 2007).
In Australia, the number of deaths is *likely* to double in 2020 from 1,115 per year at present, and increase to between 4,300 to 6,300 per year by 2050 (McMichael et al., 2003; Whetton et al.
2005). 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 warming of 1, 2 and 3°C, respectively (McMichael et al., 2003). An ageing society in Australia and New Zealand is *likely* to amplify these figures. For example it has been predicted that 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 between 131 and 246 per 100,000 (Woodruff et al., 2005). In Australia cities with a temperater climate are likely to experience more heat related death than those cities with a tropical climate (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 can cause significant disruption to this industry. 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). 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 have a negative impact on water security in the Murray-Darling Basin in Australia, as it accounts for most of the water for 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 cause land-use change in southern Australia. Cropping could become non-viable at the dry margins if rainfall substantially decreases, 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$320 million damage (Lavorel and Steffen, 2004), with about 500 houses destroyed, four people killed and hundreds injured. Three of the city's four water storage reservoirs were contaminated for several months by sediment-laden runoff (Hennessy et al., 2007). The 2009 fire in the state of Victoria caused immense damage (see Chapter 9, Box 4.1)

An increase in fire danger in Australia is associated with a reduced interval between fire events, 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 15-70% by 2050 (Hennessy et al., 2006). By the 2080s, the number of days with very high and extreme fire danger *are likely* to increase by 10-50% in eastern areas of New Zealand, the Bay of Plenty, Wellington and Nelson regions (Pearce et al., 2005), with even higher increases (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 fuel reduction 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), with consequences for flood risk.

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 time-to-peak and shorter flood warning times, posing a difficult challenge to flood preparedness.

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 it is projected to rise by 13 to 30% by 2030, and by 30 to 80% by 2080 (Gray et al., 2005). Peak flow is projected to increase by 4% by 2030 and by 40% by 2080.

Storm surges

Over 80% of the Australian population lives in the coastal zone, and outside of the major capital cities this is where the largest population growth occurs (Harvey and Caton, 2003; ABS, 2010). Over 700,000 addresses are within 3 km of the coast and less than 6 m above sea level. Queensland and NSW make up 60% of these residents (Chen and McAneney, 2006). As a result of being so close to sea level, the risk of inundation from sea-level rise and large storm surges is increased (Hennessy et al., 2007). The risk of a one in a hundred year storm surge in Cairns is *likely* to more than double by 2050 (McInnes et al., 2003).

Tropical cyclones

No trend in the frequency of tropical cyclones in the Australian region from 1981 to 2005 has been detected, but there has been an increase in intense systems (very low central pressure) (Kuleshov, 2003; Hennessy, 2004; Harper et al., 2008).

Coping with extremes

Australia and New Zealand have a long history of flood management, though early effort was 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 overlooked at the local planning level leading to intensive development in 'protected areas' and increased vulnerability to supra-design events (Ericksen, 1986). Economic restructuring in New Zealand in the second half of the 1980s resulted in the removal of subsidies, and local government reform resulted in the merging of catchment management with other regional planning activities. Introduction of the New Zealand 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 and Forestry and to social welfare services (Ministry of Social Development) where their income is severely reduced. Where a farm is considered to be unsustainable, 'new start' grants are made available to assist farmers to leave the industry (Ministry of Agriculture and Forestry, 2010).

[INSERT TABLE 4-14 HERE:
Table 4-14: Climate extremes, vulnerability, and impact]

Regional costs for the Oceanic region

The Oceanic region, including Australia, New Zealand and the Pacific Island countries and territories (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 climate-related disasters in Australia is not evenly spread, as a few large events dominate the overall cost, including Cyclone Tracy and the Brisbane floods in 1974, the Sydney hailstorm in 1999, the "Ash Wednesday" wildfires in 1983, and Canberra fire of 2003, 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 & 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 & McAneney, 2008). Climate change is concurrently expected to increase the frequency and severity of extreme weather events (Alexander & 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 and 2009 to be approximately US$1 billion. 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 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), 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 & 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 been 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, 2009). Much of this traditional resilience remains and could be reinvigorated within the current context to reduce vulnerability (also see section 4.5.10).

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 impact 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 (Figure 1; Vaquer-Sunyer and Duarte, 2008).

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 which 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, 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 (cf. Chapter 3). The MOC is the northward flow of water in the surface Atlantic Ocean, bringing warm water from the tropics towards the Arctic where it cools progressively as it moves north due to heat-loss to the atmosphere, eventually sinking to the deep ocean and tracking 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 every 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 (Keller et al., 2010), but associated uncertainties are high (Brennan et al., 2008). An increased cloud cover and significant surface cooling throughout Western

Europe would have potentially catastrophic environmental and economic impact (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. Chapter 3). 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 Arctic ice thickness was reduced, on the average, by 110 cm, as compared with its average thickness of about 3 m (Nagurnyi, 2009). Information on the prospects of navigation in the Arctic Ocean is given in 4.5.9.

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. For navigation aspects of the extensive melting of Arctic sea ice, see 4.5.9.

4.5.9. Polar Region

Introduction

The Polar region consists of the Arctic, around the North Pole and the Antarctic, around the South Pole. The Arctic region consists of a vast north treeless permafrost territory (north of Europe, Asia and North America, and several islands (including Greenland). Slow climate changes in the Polar Regions can lead to extreme impacts. Increasing temperatures in this region are accompanied by phase transition of water into ice and back into water and sharp changes of the environment and impacts on human systems and ecosystems.

In the last century, the Arctic has *very likely* warmed and air temperature in the region has risen at almost twice as fast as the global temperature (Hassol, 2004), although the warming has not been uniform. Land stations north of 60º N indicate that the average surface temperature increased by approximately 0.09 ºC per decade during the past century, which is greater than the 0.06 ºC per decade increase averaged over the Northern Hemisphere (McBean et al., 2005). 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 A.B., 2009) and seasonal thaw depth (permafrost degradation) was observed. Sea ice coverage in the Arctic Ocean has shrunk, improving navigation in the Arctic Region (see Section 5.4.8). Other changes observed include; increase of inter-annual variability, 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 on humans are not equally noticeable in the Polar Regions as elsewhere throughout the world. The territory of the Russian Arctic is more populated than other Polar Regions. Impacts of climate change are most noticeable here as they affect human activities.

A positive impact of climate change is the decrease of the duration of the heating season and in the number of heating degree-days (HDDs) when heating is necessary to maintain a comfortable temperature (almost throughout the entire Arctic region) (Sherstyukov, 2007).

Warming cryosphere

For several key Arctic systems, notably Arctic sea ice and the Greenland Ice Sheet, recently observed changes have been happening at rates significantly faster than predicted in previous expert assessments, notably IPCC AR4 (Stroev et al., 2007, Anisimov et al., 2007). 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 (Stroev et al., 2007).

Analysis of the extent of melt of the Greenland Ice Sheet using passive microwave satellite data has shown a dramatic increasing trend since 1979 which appeared to be interrupted only in 1992 by the eruption of Mt. Pinatubo. Extreme melt years were 1991, 1995 (Abdalati and Steffen, 2001) and in 2002 (Steffen et al., 2004).

Recent changes in the Greenland Ice Sheet have been complex. During the period between April 2002 and February 2009 the mass loss of the Greenland and Antarctic ice sheets was not a constant, but accelerating with time. This suggests that the observations are better represented by a quadratic trend rather than by a linear one, implying that the melt from ice sheets contributes to sea level rise at a larger rate each year. Gravity satellite ice sheet mass measurements have shown that in Greenland, the mass loss increased from 137 Gt/yr in 2002-2003 to 286 Gt/yr in 2007-2009. In Antarctica the mass loss increased from 104 Gt/yr in 2002-2006 to 246 Gt/yr in 2006-2009 (Velicogna, 2009).

The colder interior has thickened, most probably as a result of recently higher precipitation rates, while the coastal zone has been thinning. There is a growing body of evidence (Anisimov et al., 2007) that thinning is now dominating the mass balance of the entire ice sheet. This evidence comes from accelerating coastal thinning, which are responses to recent increases in summer melt, and an accelerated discharge of many coastal glaciers. Using satellite radar interferometry observations of Greenland, Rignot and Kanagaratnam (2006) detected widespread glacier melt below 66° north between 1996 and 2000, expanding 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 (Rignot and Kanagaratnam, 2006).

Climate warming leads to permafrost degradation. In the Russian North, the seasonal soil thawing depth increased has by 40-80 cm and the isotherm that characterizes a southern boundary of insular permafrost has shifted northward

(Sherstyukov, 2009). Permafrost degradation is increasing and is projected to accelerate in some areas. Geothermal modeling predictions indicate that thaw depth will increase dramatically and permafrost may disappear at some sites in Canada (Burgess et al., 2000).

Warming and thawing of the frozen ground in the Arctic region results in considerable mobilisation of greenhouse gases (Anisimov et al., 2007). The end-products of decomposition of the ancient organic substance are CO2 (in aerobic conditions) and CH4 (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 CO2 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. In the 1990s, the number of damaged buildings increased by 42% - 90% in comparison with the 1980s in the north of Western Siberia (Anisimov and Belolutskaya, 2002; Weller and Lange, 1999).

An apartment building collapsed 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 the buildings in Pevek, Amderm, Magadan, and Vorkuta have also been damaged (Anisimov and Belolutskaya, 2002; Anisimov and 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 increased 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 Regions, in 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 routes 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 melted tundra.

Ice cover does not allow navigation of the ships. Navigation in the Arctic Ocean is only possible during the ice-free period of the northern coasts of Eurasia and North America. 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 sea transport going through the Northern Sea Route along the Eurasian coasts and through the Northwestern Passage in the north of Canada and Alaska (Impact of Climate Arctic, 2004). In September 2007, when the Arctic Sea ice area was extremely low, the 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 of timber, oil, and gas). However, owing to deglaciation in Greenland, New Land and Northern Land, the number of icebergs may increase (Strategic Prediction, 2005; Assessment Report, 2008).

Seasonal snow cover impacts the local climate through its insulating properties and high reflection and is highly variable. Over the past three decades, in Eurasia (and to a lesser extent North America) there has been an ongoing trend five to six less days per decade of snow days (Dye, 2002). These snow-free days occur primarily in spring. Projections from different climate models generally agree that these changes will continue with increasing tempretures (IPCC, 2007). Impacts are positive for agriculture as a result of increases in near-surface ground temperature, changes in the timing of spring meltwater pulses, meaning additional growth and ease of transportation (Anisimov et al., 2005).

In the north of Eurasia, duration of snow cover has decreased in recent decades (Shmakin, 2010) and accumulation of snow in spring is capable to thaw rapidly 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 rapid thawing of snow (Shmakin, 2010).

The extreme 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 and Palm, 2006). As warming in the Russian Arctic degrades permafrost, vast territories of tundra may be replaced by taiga forests.

Floods

From mid 1960s to the beginning of 1990s, winter runoff of the three largest rivers of Siberia (Yenisei, Lena, Ob; jointly making 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 thermohaline circulation (THC). The processes occurring on the scale of the Arctic region are capable to change the climate system at the planetary scale (Knight et al., 2005; Vellinga and Wood, 2002).

By 2150, an additional sea level rise of ~80cm around European coasts is evident in the THC-collapse simulation. By the end of the 21st century, the additional THC-related sea level rise is projected to be 50cm. If this is superimposed upon an approximate estimate of a regular greenhouse gas sea level rise for the same period, ~50cm, the additional financial requirement for European land protection and population relocation would be US$670 million per year, using calculations based on Stern (2007). The sign and magnitude of these sea-level rises are comparable with other investigations into the response of North Atlantic sea level to abrupt changes in the AMOC (Vellinga and Wood, 2007; Levermann et al., 2005).

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 Western Siberia and the Far East (except for the Yenisei and the Lena rivers). However, in the last three decades, maximum streamflow values began to increase over most of Arctic Russia (Semyonov and Korshunov, 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).

An increased number of damage-causing floods was recorded in Western Siberia, 86, Eastern Siberia, 67, and in the Northern area, where 10 out of 17 floods occurred in the Arkhangelsk Region. (IPCC Assessment Report, 2008).

Coastal erosion

Coastal erosion is a significant problem in the Arctic, where coastlines are highly variable and their dynamics result of environmental forcing (wind, waves, sea-level changes, sea-ice, etc.), geology, permafrost and other elements (Rachold et al., 2005).

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 adverse impact on coastal villages and towns. In addition, oil test wells are threatened (Jones et al., 2009).

The impact on local costal communities is significant as they are facing a real threat of losing their homes and even their communities due to costal erosion and SLR. Climate refugees may emerge if climate change significantly damages housing. There have already been climate refugees in the 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 (Russian Federation) (Revich, 2008). It would most likely be devastating to a local economy to move an entire village or town.

The amount of coastal erosion along a 60km stretch of Alaska's Beaufort Sea doubled between 2002 and 2007. Contributing factors are; melting sea ice, increasing summer sea-surface temperature, SLR, and increases in storm power and in turn stronger waves (Jones et al., 2009).
It is apparent that ice-rich costal bluffs are degrading faster than ice-poor costal bluffs. An explanation for this phenomenon may be the recent trends toward increasing sea-surface temperatures and SLR.

Permafrost degradation along the coast of the Kara Sea may lead to intensified coastal erosion, driving the coastline back by 2-4 meters per year (Anisimov and Lavrov, 2004). This coastline retreat poses considerable risks for coastal population centres in Yamal and Taymyr and other littoral lowland areas.

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 extremes (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 (FitzGerald, 2008). Island infrastructure tends to predominate in coastal locations (Hess et al., 2008), 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 exacerbates inundation, erosion and other coastal hazards, threatens vital infrastructure, settlements and facilities, and thus compromises the socio-economic well-being of island communities and states (Hess et al., 2008). There is also strong evidence that under climate change, water resources in small island states, especially those that are vulnerable to future changes and distribution of rainfall, will be seriously compromised (FitzGerald, 2008). For example, many small islands are likely to experience increased water stress as a result of climate change (Mimura et al., 2007, Kundzewicz et al., 2007, 2008).

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 (PICs), with total population of 9.7 million in 2009 exhibit considerable demographic variety. Almost 8.5 million people lived in Melanesia 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, such as 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 (SPC, 2009).

PICs have a variety of characteristics rendering generalization difficult (see Table 4-15). One form of PICs is large inter-plate boundary islands formed by subduction and found in the south west Pacific Ocean. These may be compared to the Oceanic (or intra-plate) islands which were, or are being, formed over ‘hot spots’ in the earth’s mantle to volcanic high islands. Some of these are still being formed and some of which are heavily eroded with steep slopes and barrier reefs. Another form of PICs are 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, with atolls being 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 in 2004, the 20m cliffs were unable to provide protection.

[INSERT TABLE 4-15 HERE:
Table 4-15: Pacific Island type and exposure to risks arising from climate change.]

Exposure

Drought is a hazard of considerable importance in SISs. Atolls, in particular, have very limited water resources being dependent on their Ghyben-Herzberg fresh water lens, whose thickness decreases with sea-level rise (cf. Kundzewicz et al., 2007, 2008), floating above sea water in the pervious coral, and is replenished by convectional rainfall. High islands in PICs 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 than the central and eastern parts, though this trend is reversed during El Niño events which give rise to serious droughts in the western Pacific, and possible devastating frosts in the Papua New Guinea Highlands (ref), the most densely populated region in the country, dependent upon sweet potatoes. During drought events, water shortages in SISs 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 (ref). In the most pressing circumstances, communities of SISs 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, since many of the SISs located along the plate boundaries are exposed to high levels of seismological activity and there are several active volcanoes. Tsunami is a risk, but for coastal communities 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 ultimately to warming temperatures (see Section 4.3.3.1).

Changing vulnerabilities

Communities in PICs 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 and storing surpluses. 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. 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 thereby increasing exposure to storm surges.

With the advent of colonialism, 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 PICs as post-disaster rehabilitation planting material.

Urbanization has increased rapidly in the past two decades (Connell and Lea, 2002), and is changing the nature of vulnerability in many PICs. 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 PICs has a rural focus and while some traditional 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 PICS 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, of which 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. The death toll in climate related events in the 2000s in the region was 324 people. These events affected at least 690,000 people (97 per cent of all natural disasters) and 66,000 were displaced. No data on fatalities are available for the period of severe and widespread drought associated with the 1997-98 El Niño events.

Regional costs for PICs are reviewed in Section 4.5.7.

Disaster management

Disaster relief began in the colonial period but tended to be ad hoc and reactive and contributed to the neglect of some of the traditional measures. Food preservation has declined as well as 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.

However, major investments in disaster preparedness and response in recent decades in many 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).

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 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.

4.6. Total Cost of Climate Extremes and Disasters

4.6.1. Economic, Social, and Environmental Consequences of Extremes and Disasters

The following subsection focuses on the economic impacts of weather extremes and disasters on humans, societies and ecosystems. These comprise of observed and projected economic impacts, including economic losses and future trends of extreme events and disasters in key regions. The subsection stands at an interface between chapters, utilizing the conceptual framework of Chapters 1-2, the scientific foundation of Chapter 3 and earlier subsections in this chapter, and leads into the following adaptation Chapters 5-8.

The total costs are defined as the economic, social and environmental impacts of a climate extreme or disaster. In the language of this section, total costs consist of all direct, indirect and intangible costs or impacts.

4.6.1.1. Framing the Social and Economic Impacts of Extremes

Economic impacts, generally measured as costs, from *climatic extreme events and disasters* arise due to disaster impacts, as well as the efforts associated with adaptation. In line with general definitions in the report in Chapters 1 and 2, economic disaster *risk* may be defined as the *potential* economic cost usually measured by a probability distribution taking account of hazard, exposure and vulnerability. There are different definitions in the literature, but economic costs can generally be broken down into damage costs or losses, adaptation costs, and residual damage costs.

> "From an economic perspective, a disaster implies some combination of *losses* in terms of human, physical, and financial capital, and a reduction in economic activity, such as income and investment, consumption, production, and employment in the "real" economy" (Benson and Clay, 2003).

The *economic impact of extremes and disasters* on economies, societies and ecosystems can be the observed or modeled impacts, and measured as the loss of economic assets or stocks, as well as consequential indirect effects on economic flows, such as on GDP or consumption (ECLAC, 2003). Note that impacts on the informal or undocumented economy may be very important in some areas and sectors. Economic impacts can be identified as direct when stocks are impacted and indirect when flows are affected. Many important impacts are difficult to measure as they are not given monetry values such as human lives, cultural heritage and ecosystem services. These items are often referred to as intangibles (Cavallo and Noy, 2010; World Bank, 2010; Benson and Clay, 2003; ECLAC, 2003; Handmer et al. 2003; Pelling et al., 2002).

Direct economic losses, or damage costs, refer to the physical destruction of assets, including private dwellings, small business properties, industrial facilities, and government assets, such as infrastructure (e.g. roads, bridges, ports, telecommunications) and public facilities (e.g. hospitals, schools) (ECLAC, 2003; World Bank/UN, 2010). Direct losses are often defined as those that are a direct consequence of the natural phenomenon (i.e., an earthquake, a flood, or a drought), including "fixed assets and capital (including inventories), damages to raw materials and extractable natural resources, and of course mortality and morbidity" (Cavallo and Noy, 2010). Direct impacts are comparatively easy to measure, but costing approaches are not necessarily standardized and assessments are often incomplete, which can make aggregation and comparability across the literature difficult. In some countries flood impact assessment has long been standardized, for example in Britain and parts of the US (e.g. Handmer et al., 2002).

Indirect damage costs or losses refer to the impacts on economic activity, in particular the production of goods and services,that will not take place following the disaster (ECLAC, 2003; UN/World Bank, 2010). In addition, business pessimism could dampen investment and consequently growth (Gaiha, Hill & Thapa, 2010). These indirect damages may be caused by the direct damages to physical infrastructure, or because reconstruction pulls resources away from production. Indirect damages includes additional costs incurred from the need to use alternative and potentially inferior means of production and/or distribution of normal goods and services (Cavallo and Noy, 2010). Indirect impacts generally refer to disruption of the flows of goods and services (and therefore economic activity) because of a disaster, and are sometimes termed consequential or secondary impacts as the losses typically flow from the direct impact of a climate event. For example electricity transmission lines may be destroyed by wind, a direct impact, causing a key source of employment to cease operation putting many people out of work and in turn creating other problems which can be classified as indirect impacts. These impacts can emerge later in the affected location, as well as outside the directly affected location (Cavallo and Noy, 2010; Pelling et al., 2002; ECLAC, 2003). These include both negative and positive factors, such as transport disruption, 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). Other examples of indirect losses are long running droughts inducing local economic decline, out migration or famine, the partial collapse of irrigation areas or livelihoods dependent on hydro electricity.

Many important impacts are difficult to measure in money terms as they are not normally traded in markets such as human lives, cultural heritage and ecosystem services. These items are often referred to as intangibles (Benson and

Clay, 2003; 2010; Cavallo and Noy, 2010; Pelling et al., 2002; ECLAC, 2003; Handmer et al. 2003). Intangible losses must be estimated using valuation techniques such as loss of life/morbidity (usually estimated using value of statistical life benchmarks), replacement value, benefits transfer, contingent evaluation, travel cost, hedonic pricing methods, and so on (there is a vast literature on this subject, e.g., Pagiola et al. 2004; Carson *et al*, 2003; Handmer *et al*, 2002; Ready and Navrud, 2006; TEEB, 2009). Tangibles are those for which markets normally exist and are therefore conventionally expressed in terms of money, or in the case of barter informal economies, could be expressed in money.

Studies and reports on the economic impacts of extremes, such as insurance or emergency reports, have mostly focused on direct losses. However, the loss from indirect impacts and intangible impacts could far outweigh direct impacts, considering the losses from social goods and natural capital (in particular ecosystem services), as well the longer term economic impact of disasters. Indirect economic loss assessment methodologies exist but with large uncertainty and method-dependent results. Assessing intangible impacts in the social, cultural and environmental fields is more difficult and there is little agreement on methodologies (Albala-Bertrand, 1993; Tol, 1994; Masozera et al, 2007; Schmidt et al, 2009; Hall et al, 2003; Huigen and Jens, 2006). The World Bank (2010b) points out that indirect effects—including in areas outside the disaster zone—are not all adverse. Measuring disasters' many effects is problematic, prone to both overestimation (for example, double counting) and underestimation (it is difficult to value loss of life, or damage to the environment). Biases also affect the accuracy of estimates, for example the prospect of aid may create incentives to inflate losses.

Adaptation costs are the costs of planning (e.g. warnings), preparing for (e.g. risk prevention and reduction), facilitating (e.g. emergency disaster responses), and implementing adaptation measures (including transition costs, rehabilitation and reconstruction) (IPCC, 2001). The benefits of adaptation can generally be assessed as the value of avoided damage as well as any additional benefits generated by the implementation of adaptation measures (IPCC, 2001; also see Section 2.4.2). The value of all avoidable damage can be taken as the gross (or theoretically maximum) benefit of risk management, which may be feasible but not necessarily economically efficient (Parry, et al, 2009; Pearce et al, 1996; Tol, 2001). The *adaptation deficit is i*dentified as the gap between current and optimal levels of adaptation to climate change events or extremes (Burton and May, 2004). However, it is difficult to assess the optimal adaptation level due to the uncertainties inherent in climate scenarios, about the future patterns of exposure and vulnerability to climate events, and debate over methodological issues such as discount rates. In addition, as social values and technologies change what is considered avoidable also changes adding additional uncertainty to future projections.

In the adaptation literature, residual damage costs or losses can be distinguished from avoidable losses (Parry et al. 2009). The residual damage is the loss that would not, or cannot, be avoided when all desirable adaptation actions have been implemented.

4.6.1.2. Extremes, Impacts, and Development

The relationship between socio-economic development and disasters including those triggered by climatic events has been explored by a number of researchers (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; Cavallo, Noy, 2010; Pelling et al, 2002; Okuyama, Sabin, 2009; Sanghi, 2010). Nevertheless, due to lack of data availability and incomparable methodologies, understanding disaster consequences remains limited.

The scale and magnitude of the economic impacts of natural disasters can be estimated by the following factors (OAS, 1991; Mechler, 2004; Gurenko, 2004; Cummins and Mahul, 2008; Benson and Clay, 2004): (i) type of natural event; (ii) exposed population and assets to a specific climatic event (iii) concentration of economic activity (e.g. large urban agglomerations); (iv) size of geographical area impacted; (v) technical and scientific development; and (vi) institutional capacity in risk management and governance.

It has been suggested that natural disasters may have some impacts on the pace and nature of economic development (Benson and Clay, 1998, 2003; Kellenberg and Mobarak, 2008). (The "poverty trap" created by disasters will be discussed in chapter 8). A growing literature has emerged that identifies these important adverse macroeconomic and developmental impacts of natural disasters (Cuny 1984; 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). It is apparent that natural disasters have a negative impacts on short term economic growth (Cavallo and Noy, 2010; Raddatz, 2007; Noy, 2009), however the evidence on impacts on short term economic growth is mixed, with both negative effects (Cavallo and Noy, 2010; raddatz, 2007; Noy, 2009) and positive effects (Albala-Bertrand, 1993, 2006; Caselli and Malhotra, 2004; Skidmore and Toya, 2002; see Section 4.2). Researchers argue that poorer developing countries and smaller economies are more likely to suffer more from future disasters than developed countries, especially in relation to extreme impacts (Raddatz, 2009; Hallegatte et al, 2007; Hallegatte and Dumas, 2009; Heger et al, 2008; Loayza et al, 2009).

In general, the observed or modeled relationship between development and disaster impacts indicates that a wealthier country is better equipped to manage the consequences of extreme events by reducing the likely impacts and by managing the impacts when they occur. This is due (inter alia) to higher income levels, more governance capacity, higher levels of expertise, amassed climate proof investments and improved insurance systems which can act to transfer costs in space and time (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). While the countries with high income account for most of the total economic and insured losses of disasters (Swiss Re, 2010), in developing countries there are higher fatality rates and the impacts consume a greater proportion of GDP. This in turn imposes a greater burden on governments and individuals in developing countries. For example, during the 25 year period from 1979 to 2004 over 95% of deaths from natural disasters 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).

The general consensus is that developing countries are more vulnerable than developed countries to extremes under climate change largely because: (i) developing countries have less resilient economies that 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 currently face (World Bank 2000); (iii) more damages are caused by mal-adaptation due to the absence of financing, information, techniques in risk management and weak governance systems; (iv) there is generally little consideration of climate proof investment in regions with a fast growing population and asset stocks (such as in coastal areas) (OECD, 2008; IPCC, 2001b); (v) the adaptation deficit resulting from the low level of economic development (World Bank, 2007); and vi) large informal sectors. However, in some cases like Hurricane Katrina in New Orleans US (as mentioned in 4.6.3), developed countries also suffer severe disasters because of social vulnerability and inadequate disaster policy (Birch and Wachter 2006; Cutter and Finch, 2008).

While some literature has found that the relationship between income and natural disaster consequences is not linear in particular for geophysical or seismic hazards (Kellenberg and Mobarak, 2008; Patt et al, 2009), much empirical evidence supports a negative relationship between the relative share of GDP and fatalities, with fatalities from hydro-meteorological extreme events falling with rising level of income (Kahn, 2005, Toya and Skidmore, 2007; World Bank, 2010; Gaiha, Hill & Thapa, 2010). Some emerging developing countries, such as China, India and Thailand, will likely face increased future exposure to extremes, especially in highly urbanized areas. This comes as a result of the rapid urbanization and economic growth in those countries (OECD, 2008; Bouwer et al., 2007).

It should be also be noted the fact that in a small country, a disaster can directly affect much of the country and therefore the magnitude of losses and recovery demands can be extremely high relative to GDP and public financial resources. This is particularly the case in the event of multiple and/or consecutive disasters in short periods. For example, in Fiji, consecutive natural disasters have resulted in reduced national GDP as well as decreased socioeconomic development as captured by the human development index (Lal et al., 2009). In Mexico, natural disasters saw the Human Development Index (HDI) regress by approximately two years and an increase in poverty levels (Rodriguez-Oreggia et al, 2009). Patt et al. (2009) indicated that the vulnerability in the least developing countries will rise most quickly, which implies an urgent need for international assistance.

Costs and impacts not only vary among developing and developed countries, but between and within countries, regions, local areas, sectors, systems and individuals due to the heterogeneity of vulnerability and resilience (see Chapter 2). Some individuals, sectors, and systems would be less affected, or may even benefit, while other individuals, sectors, and systems may suffer significant losses in the same event. In general, the poorest and those who are socially or economically marginalised will be the most at risk in terms of being exposed and vulnerable (Wisner et al. 2004). For example, women and children are found to be more vulnerable to disasters in many countries, with larger disasters having an especially unequal impact (Neumayer and Plumper, 2007).

4.6.2. Methodologies for Evaluating Disaster Impacts and Adaptation Costs

4.6.2.1. Methods and Tools for Evaluating Impacts

Modeling disaster impacts generally involves generating an estimate in terms of risk using probability based metrics. Analyses considering climate change in economic impact and risk modeling have only emerged over the last few years, and, as reported in 2007 by Solomon et al., much of the literature remains focused on gradual changes such as sea-level rise and agricultural effects. In early work, extreme event risks in adaptation studies and modeling have usually been represented in an ad hoc manner, using add-on damage functions that are based on averages of past impacts and contingent on gradual temperature increase (see comment in Nordhaus and Boyer, 2000). However, new studies are becoming available, that look explicitly at extreme events in assessment models that take a more integrated view (Nordhaus, 2010; Narita et al., 2009; Narita et al. 2010; Hallegatte et al., 2008; Mechler et al., 2010).

In most impact and modeling studies on extreme event risks, the focus has been on tangibles, such as impacts on produced capital and economic activity. Intangibles such as loss of life and impacts on the natural environment are generally not considered using monetary metrics (Parry et al., 2009). Loss of life due to natural disasters, including future changes, is accounted for in some studies (e.g. BTE, 2001; Handmer et al, 2008; Jonkman, 2007; Jonkman et al., 2008; Maaskant et al., 2009). Estimates of impacts that account for tangibles and intangibles are likely to be much larger than those that consider tangible impacts only (Handmer et al. 2008; Parry et al. 2009). The gap between likely impacts and those used in studies will be greater if only direct impacts are counted. For example, a recent study on future expected damages from tropical cyclones as a result of climate change measure soley direct impacts (Mendelsohn et al, 2010).

At a simple level approaches for the economic valuation for the impacts caused by extremes and disasters at the national, regional and global level fall into two categories: a “top down” approach that uses models of the whole economy under study; and a bottom-up or partial equilibrium approach that identifies and values changes in specific parts of an economy (Van der Veen, 2004).

The top-down approach is grounded in macroeconomics under which the economy is described as an ensemble of interacting economic sectors. Most studies have focused on impact assessment remodeling actual events in the past and aim to estimate the various, 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 macroeconomic or top-down approaches utilize a range of models such as Input-Output, Social Accounting Matrix (SAM) multiplier, Computable General Equilibrium (CGE) models, economic growth frameworks and simultaneous-equation econometric models. These models attempt to capture the impact of the extreme event as it is felt throughout the whole economy. 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).

The 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). The bottom-up approach to disaster impact assessment attempts to evaluate the impact of an actual or potential disaster on consumer's willingness to pay (or willingness to accept). 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.

How disaster impacts are evaluated depends on numerous factors, such as the types of impacts being evaluated, the objective of the evaluation, the spatial and temporal scale under consideration, and importantly, the information, expertise and data available. In practice, the great majority of post- disaster impact assessments are undertaken pragmatically using whatever data and expertise are available. These are then aggregated on a partial equilibrium basis.

The first step in disaster impact assessment of this kind is to establish the spatial and temporal scale of the analysis. Analysts must be clear about and consistent in their treatment of costing property and infrastructure loss. It is important to note that macroeconomic approaches such as CGE models look only at market dynamics and as such do not capture intangibles such as impacts on ecosystems. A Leontief input output or SAM multiplier approach might be able to capture these impacts, but in practice they are rarely used. It may be that the largest impacts of disasters are the intangible losses such as lives, 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 (see section 4.6.1.1). Many studies utilise both partial and general equilibrium analysis in an 'integrated assessment' that attempts to capture both the bottom-up and economy-wide impacts of disasters (World Bank, 2010; Ciscar et al, 2009).

4.6.2.2. Methods and Tools for Evaluating the Cost of Adaptation

Adaptation costs have been mainly assessed using two approaches: (i) determining the pure *financial costs*, i,e. outlays necessary for specific adaptation interventions (known as *Investment and Financial Flow (I&FF) analyses*); and (ii) *economic costs involving estimating* the wider overall costs and benefits to society often using economic Integrated Assessment Models (IAM). The latter approach leads to a broader estimate of costs (and benefits), but requires detailed models of the economy under study, and has therefore often found application in country level studies (UNFCCC, 2008). One way of measuring the costs of adaptation involves first establishing a baseline development path (for a country or all countries) with no climate change, and then altering the baseline to take account of the impacts of climate change (World Bank, 2010). Then the likely impacts of various adaptation strategies on development or growth can be examined. Adaptation cost estimates are based on various assumptions about the baseline scenario and the effectiveness of adaptation measures. The difference between these assumptions makes it very difficult to compare or aggregate results (Yohe, et al, 1996; 1995, 2011; West et al., 2001).

An example illustrating the methodological challenges comes from agriculture, where estimates have been done using various assumptions of adaptation behavior (Schneider, S.H., K. Kuntz-Duriseti, C.Azar, 2000). These assumptions about behaviour range 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 – that is that farmers have complete or "perfect" knowledge and apply that knowledge in ways that ensure outcomes align exactly with theoretical predictions (Kurukulasuriya, 2008a; Kurukulasuriya, 2008b; Mendelsohn, 1999; Seo, 2008). Realistic assessments fall between these extremes, and a realistic representation of future adaptation patterns depends 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 use of realistic behaviour by farmers.

National level studies of adaptation effectiveness in the EU in the UK, Finland and the Netherlands as well as a larger number of developing countries using the NAPA (National Adaptation Plan of Action) 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 aspects including economic efficiency of adaptation remains limited and fragmented (Adger et al., 2007; Agrawala and Fankhauser, 2008; Moench et al., 2009; UNFCCC, 2009). Many adaptation studies focus on sea level rise and slow onset impacts for agriculture. Those studies considering extreme events, and finding or reporting net benefits over a number of key options (UNFCCC, 2009; Agrawala and Fankhauser, 2008), do so by treating it similar to gradual onset phenomena and use deterministic impact metrics, which is problematic for disaster risk. A recent, risk-focused study (ECA, 2009) concentrating on national and subnational levels went so far as to suggest an adaptation cost curve, which organizes relevant adaptation options around their cost benefit ratios. However, given available data including future projections of risk and the effectiveness of options is likely to be at most heuristic rather than a basis for policy.

Disasters and cost-benefit analysis

Cost-benefit analysis (CBA) is an established tool for determining the economic efficiency of development interventions. CBA compares the costs of conducting such projects with their benefits and calculates the net benefits or economic efficiency (Kramer 1996; Benson and Twigg 2004; FEMA 2007). All costs and benefits are monetized so that tradeoffs can be compared with a common measure. Ideally CBA accounts for all costs and benefits to society including environmental impacts, not just financial impacts on individual businesses (Mechler et al, 2008). The fact that intangibles and other items that are difficult to value are often left out is one of the major criticisms of the approach. And World Bank (2010b) notes while arriving at the right choice when disaster prevention saves lives requires valuing them, ethical and philosophical factors must be considered in attaching a value to life. In the case of disasters and DRR interventions, CBA weighs the costs of the DRR project against the disaster damage costs avoided. While the benefits created by development interventions are the additional benefits due to, for example, improvements in physical or social infrastructure, in DRM the benefits are mostly the avoided or reduced potential damages and losses (Altay et al. 2004). The net benefit can be calculated in terms of net present value, the rate of return or the benefit-cost ratio.

OECD countries such as the United Kingdom and the United States, as well as international financial institutions such as the World Bank, Asian Development Bank and Inter-American Development Bank, have used CBA frequently for evaluating DRM in the context of development assistance (ADB 2003; Venton and Venton 2004; Ghesquiere et al. 2006; Montes et al. 2006), and use it routinely for assessing engineering DRM strategies domestically. CBA can be, and has been, applied at any level from the global to local.

Because disaster events are probabilistic, and hence benefits of DRR are probabilistic, costs and benefits should be calculated by multiplying probability by consequences; this leads to risk estimates that account for hazard intensity and frequency, vulnerability and exposure (Altay et al., 2004; Ghesquiere et al., 2004).

There are several complexities and uncertainties inherent in the estimates required for a CBA of DRR. As these are compounded by climate change, CBA's utility in evaluating adaptation may be reduced. Limitations in the modelling of weather extremes, and data and resource limitations are two key challenges. In addition to the point raised earlier that traditionally CBA does not handle non-monetary impacts (intangibles) well, it is important to note that as CBA does not account for the distribution of costs and benefits, equity and distributional impacts must be established separately. Furthermore, while CBA ideally accounts for all impacts on social welfare, establishing value for intangible impacts such as those on ecosystem services poses a methodological and resource challenge. Finally the issue of discounting the future is a key issue for CBA because essentially higher discount rates favor strategies with rapid payoffs, while very low rates favour strategies that provide benefits over a long time horizon (Kramer, 1995; Handmer and Thompson, 1997; Benson and Twigg, 2004; Venton and Venton, 2004; Mechler et al, 2008; UNFCCC, 2008).

Moench et al (2009) argue that due to the challenges and complexities inherent in the use of CBA for DRR it is more useful as a decision support tool that helps the policy-maker categorize, organise, assess and present information on the costs and benefits of a potential project, rather than one that gives a definite answer.

4.6.3. 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. Overview of the Regional and Global Economic Loss of Climate Disasters (observed and potential trends)

Observed trends in extreme impacts: Global observed climate related disaster impacts over the last few decades reflect mainly monetized direct damages to assets, and are unequally distributed. Annual accumulated estimates have ranged from a few billion to about 250 billion USD (in 2009 values) for 2005 (the year of Hurricane Katrina (see Section 4.2.4, Munich Re, 2010; Swiss Re 2010; UN-ISDR, 2009). These estimates do not include indirect and intangible losses.

There is a consensus that developing regions are vulnerable both because of climate-related extremes and their status as developing economies as set out above in Sections 4.2. (Also see Chapter 3 for details of climate events.) However, disaster impacts are unevenly distributed by type of disaster, region, country and the exposure and vulnerability of different communities and sectors.

Percentage of global damages by regions: The concentration of disaster risk generally has a geographical focus (Swiss Re, 2008, WB 2010, etc). However, the distribution of evaluated impacts is fragmented due to the difficulty in attributing causes of fluctuations in economic losses from disasters, and an imbalanced spatial coverage by the relevant literature, which is skewed mostly toward developed countries and the northern hemisphere. Based on the numbers and damage losses of disasters, the unequal distribution of the human impact of natural disasters is reflected in the number of disasters and damage losses between regions (see Table 4-16). The Americas suffered the most economic damage from climatological, meteorological and hydrological disasters, accounting for a highest proportion (54.6%) of the total damages, followed by 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 period of 2000-2008 (Vos et al, 2010).

[INSERT TABLE 4-16 HERE:
Table 4-16: Climate Related Disaster Occurrence and Regional Average Impacts From 2000-2008]

Damage losses percentage of GDP by regions: When expressed as a proportion of exposed GDP, estimated losses of natural disasters (predominantly hydro-meteorological disasters) in developing regions (particularly 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 4-14). 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 4-14 HERE:
Figure 4-14: Distribution of Regional Damages as a % of GDP (1970-2008) (Source: EM-DAT, WDI database, calculated by Cavallo and Noy, 2009)]

Increasing trends in disaster impacts and climate change: It has been found that in recent decades there is an increasing trend in reported extremes events. This is coupled with an increasing numbers of people affected and overall economic losses from weather related disasters, which have increased more rapidly than losses from non-weather disasters (Munich Re, 2008; Swiss Re; 2008; 2009; 2010; Mills, 2005). It is suggested that changing frequency of extreme weather is already noticeable in loss records (see Figure 4-15).

However, attribution of changes in disaster impacts to climate has proven difficult and the weight of evidence at present is that increases should not be attributed to climate change. The issues are reviewed in Section 4.2.4.

There are a number of issues with these analyses. 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 and carry the limitations discussed earlier in Section 4.6. Most analyses pay limited attention to droughts. But that is different from the measuring the "costs of managing events", which would depend on the range and type of interventions, and for which there are no existing global estimates.

[INSERT FIGURE 4-15 HERE:
Figure 4-15: The Overall Losses and Insured Losses from Natural Disasters Worldwide (adjusted to present values) (Source: Munich-Re, 2007)]

[INSERT FIGURE 4-16 HERE:
Figure 4-16: Historical Trends of Climatological Disasters (normalized)]

In conclusion, as highlighted in Section 4.2.4 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.

Potential trends in key extreme impacts: As indicated in sections 4.3-4.5, the major extremes may have a different trend in the future; some such as heatwaves are predicted to increase in frequency and intensity, while others such as flooding may not. However, uncertainty is a key aspect of disaster/climate change trend analysis due to attribution issues discussed above, incomparability of methods, changes in exposure and vulnerability over time, and other non-climatic factors such as mitigation and adaptation. Recent work has considered future exposure and potential impacts of sea level rise in coastal cities, flooding (Hallegatte, et al, 2010; OECD, 2008), and losses due to climate-related extremes in least developing countries (Patt et al, 2009), etc. It is very likely that the socio-economic development trends will translate into increasing exposure and vulnerability in population and assets especially in those coastal urbanization areas in the next decades.

Section 4.2.4 examines attribution of losses to climate change, and Section 4.3.2.2 examines cyclone impacts in depth. The evidence is that to date no trends in impacts can be attributed to climate change. There are many methodological issues with these studies. One estimate of the increase in damage associated with changed tropical cyclone activity as a result of climate change is between $28 billion and $68 billion annually by 2100 World Bank (2010b). This represents an increase of between 50 and 125 percent over no climate change. 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 and the effects are likely to be concentrated: several small island countries in the Caribbean are particularly vulnerable. Another study, building on GCM results from Bender et al. (2010), finds that although losses from tropical storms (hurricanes) in the USA could increase significantly, they are unlikely to be detectable with certainty until 260 years from now, due to the high natural variability of storms and their impacts (Crompton et al., 2010). This result itself needs to be interpreted in the context of the significant uncertainties with the modelling involved.

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 addresses future 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. Some studies are available on future coastal flood risks in the UK (Hall et al., 2005; Mokrech et al., 2008; Dawson et al., 2009).

Some studies have addressed economic losses from other types of weather extremes, often smaller scale compared to river floods and windstorms. 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 by mid-century.

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 (see Sections 4.2 to 4.5). 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).

[INSERT TABLE 4-17 HERE:
Table 4-17: Estimated Change in Disaster Losses in 2040 Under Projected Climate Change and Exposure Change, Relative to the Year 2000 from Twenty-One Impact Studies, Including Median Estimates per type of Weather Hazard (Sources: Bouwer, 2010)]

4.6.4. The Regional and Global Costs of Adaptation

There have been a limited number of adaptation costs assessments over the last few years with a global and regional level resolution; yet those studies have not explicitly separated extreme events from gradual change (see Parry et al., 2009; World Bank, 2009; EEA, 2007; ECA, 2009; Solomon 2007; Nordhaus, 2007; Parry et al., 2009; Agrawala and Fankhauser, 2008; World Bank, 2010). As well, 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 the issuein a similar way to gradual onset phenomena and use deterministic impact metrics.. Estimates range from 4 to 100 billion USD per year with a bias towards the higher costs.

[INSERT TABLE 4-18 HERE:
Table 4-18: Estimates of global costs of adaptation]

There are only three independent estimates of the global costs of adaptation. World Bank (2006) estimates the cost of climate proofing foreign direct investments (FDI), gross domestic investments (GDI) and Official Development Assistance (ODA), which was taken up and modified by the Stern Review (2006), Oxfam (2007) and UNDP (2007). The second source of cost estimates is from UNFCCC (2007), which calculated the value of existing and planned investment and financial flows required for the international community to effectively and appropriately respond to climate change impacts. World Bank (2010) follows the UNFCCC (2007) methodology and improves upon this by using more precise unit cost estimates, the inclusion of costs of maintenance as well as those of port upgrading as well as the risks from sea-level rise and storm surges.

Regionally, the World Bank (2010) study estimates that for both “wet” and “dry” scenarios the largest absolute costs would arise in East Asia and the Pacific, followed by the Latin American and Caribbean region as well as Sub-Saharan Africa.

[INSERT TABLE 4-19 HERE:
Table 4-19: Regionalized Annual Costs of Adaptation for Wet and Dry Scenarios]

As discussed by Parry et al (2009) the estimates are thus somewhat linked, which explains the seeming convergence of the estimates in latter studies. As well, Parry et al. (2009) consider the estimates a significant underestimation by at least a factor of two to three and possibly higher if the costs incurred by other sectors were included: such as ecosystem services, energy, manufacturing, retailing and tourism; and considering that the adaptation cost estimates are based mostly on low levels of investment due to an existing adaptation deficit in many regions. Thus the numbers have to be treated with caution. Unavoidable residual damages remain in these analyses, and they also need to be factored in.

It is necessary to incorporate an analysis of the ongoing or chronic economic impact of disasters 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 disaster risk reduction 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 range from US$3 to 10 billion per year by 2030 (Reid et al., 2007; UNFCCC, 2007; PACJA, 2009). However, this could be also an underestimate considering the desirability of improving Africa's resilience to climate extremes as well as the flows of 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. Adapting Africa's agriculture is likely to pose a much greater cost burden.

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 costing of climate change related disasters is still preliminary, incomplete and subject to a number of uncertain assumptions (Parry et al, 2009; Agrawala and Fankhauser, 2008; Tol, 2005). This is largely due to modeling inaccuracies in climate science and damage estimates, limited data availability and shortcomings in methodology in analyzing disaster damages statistics. Climate change costing is further limited by the interaction between numerous adaptation options and assumptions about future exposure and vulnerabilities, social preferences and technology, as well as levels of resilience in specific societies.

Risk assessment methods: Technical challenges remain in developing robust risk assessment and damage costings. Results could vary significantly between using top-down or a bottom-up approach. Risk-based approaches have been utilized for predicting the damages of disaster risk (Jones, 2004; Carter et al., 2007) of which evidence is based on both climate and social scenarios. Climate models are not good at reproducing spatially explicit climate extremes yet, due to inadequate (coarse) resolution and physical understanding in the relevant process, as well as challenges in modeling low probability, high impact events (Weitzman, 2009). Hence projections of extreme events in future climate conditions are highly uncertain, hindering projections of sudden onset risk, such as flood risk. Nonetheless, slower onset phenomena (e.g. drought) that are characterized by mean weather conditions, are better projected (Christenson, 2003; Kundzewicz et al., 2006). All climatic phenomena are subject to the limitation that historically based relationships between damages and disasters cannot be used with confidence to deduce future risk of extreme events under the changing characteristics of frequency and intensity (UNDP, 2004). Socio-economic scenarios are also built with uncertainty highlighted by debates surrounding the selection of the discount rate (Heal, 1997; Tol, 2003; Nordhaus, 2007; Stern, 2007; Weitzman, 2007) , the speed of damage restoration and so on. A uniform set of assumptions can help to provide a coherent global picture and comparison and extrapolation between regions.

Data availability and consistency: Data shortages and information gaps increase the uncertainty of costing when scaling up to global levels from a very limited (and often very local) evidence base. There are double counting problems and issues of incompatibility between types of impacts in the process of multi-sectoral and cross-scale analyses, especially for the efforts to add both market and non-market values (e.g. ecosystem services) (Downton and Pielke Jr., 2005; Pielke Jr. et al., 2008; Parry et al, 2009). Moreover the full impacts of climate change related extremes in developing countries are still poorly understood, as a lack of comprehensive studies on damage, adaptation and residual costs means the costs are underestimated.

Information on future vulnerability: Apart from climate change, vulnerability and exposure will also change over time, and interaction of these aspects should be considered in future (see Mechler and Hochrainer, 2010; Hallegatte, 2008; Dawson et al, 2009; etc). It has also been noted that assessments of climate change impacts and vulnerability have changed in focus. In initial studies, an analysis of the problem was made, followed by assessment of potential impacts and risks, and lately the consideration of specific risk management methods have moved into the spotlight (Carter et al., 2007). System risk, such as environmental incidents and financial crises, makes the future risk situation more complicated and unpredictable.

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Table 4-1: Trend of Reported Disasters from Tropical Cyclones versus Events as Detected by Satellite for the Last Four Decades.
The percentage of reported disasters increased three-fold.

	1970-79	1980-89	1990-99	2000-09
Number of Tropical cyclones (TC) event as detected by satellite (average per year)	88.4	88.2	87.2	86.5
Number of countries hit by TC as detected by satellite (average per year).	142.1	144.0	155.0	146.3
Number of disaster triggered by TC, as reported by EM-DAT (average per year)	21.7	37.5	50.6	63.0
Percentage of reported disasters as compared with number of countries hit by TC	15%	26%	33%	43%

(sources: Peduzzi et al. 2011)

Table 4-2: Average Physical Exposure to Tropical Cyclones Assuming Constant Hazard (in million people per year)

IPCC_Region	1970	1980	1990	2000	2010	2020	2030	Absolute changes 2010-2030	Relative changes 2010-2030
Africa	0.5	0.7	0.8	1.1	1.5	1.9	2.3	0.8	+ 53.3%
Asia 1	4.0	5.1	6.4	7.7	9.0	10.1	11.0	2	+ 22.2%
Asia 2	64.0	76.1	87.4	97.0	104.7	111.1	115.0	10.3	+ 9.8%
Australia and NZ	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	+ 0.0%
Caribbean	1.4	1.7	1.9	2.1	2.3	2.4	2.5	0.2	+ 8.7%
Europe	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	+ 0.0%
Indian Ocean Isl	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0	+ 0.0%
North America	2.6	3.0	3.3	3.8	4.2	4.6	4.9	0.7	+ 16.7%
Pacific islands	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.1	+ 25.0%
South america	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0	+ 0.0%
World	**73.2**	**87.2**	**100.7**	**112.8**	**122.7**	**131.3**	**136.9**	14.2	+ 11.6%

(sources: Peduzzi et al. 2011)

Table 4-3: Average Physical Exposure to Tropical Cyclones as Observed and as Projected Assuming Change in Frequency (median of all models, in million people per year and percentage changes)

IPCC_Region	1970-79	1980-89	1990-99	2000-09	2010	2030	Absolute Changes	Relative Changes
Africa	0.3	0.7	1.1	2.5	1.5	2.2	0.7	+ 46.7%
Asia 1	1.5	8.8	11.6	9.0	9	10.8	1.8	+ 20.0%
Asia 2	68.7	71.6	89.3	117.7	104.7	110.8	6.1	+ 5.8%
Australia and NZ	0.1	0.1	0.1	0.1	0.1	0.1	0	+ 0.0%
Caribbean	1.1	1.4	1.4	4.0	2.3	2.5	0.2	+ 8.7%
Europe	0.0	0.2	0.4	0.2	0.1	0.1	~0	+ 0.0%
Indian Ocean Isl	0.3	0.4	0.4	0.4	0.5	0.5	~0	+ 0.0%
North America	2.5	5.0	4.1	9.0	4.2	4.9	0.7	+ 16.7%
Pacific islands	0.1	0.3	0.4	0.2	0.4	0.5	0.1	+ 25.0%
South and Central America	0.0	0.0	0.0	0.1	0.1	0.1	~0	+ 0.0%
World	**74.6**	**88.4**	**109.0**	**143.0**	**122.7**	**132.4**	**9.7**	**+ 7.9%**

(sources: Peduzzi et al. 2011)

Table 4-4: Average Percentage Exposure to Different Category of Tropical Cyclones by Regions (1970 - 2009)

IPCC_Region	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5
Africa	81.5%	14.1%	4.2%	0.3%	0.0%
Asia 1	80.3%	14.4%	4.2%	1.1%	0.0%
Asia 2	77.6%	17.3%	4.8%	0.2%	0.0%
Australia and NZ	87.8%	8.7%	3.2%	0.3%	0.0%
Caribbean	68.6%	17.3%	10.1%	4.0%	0.0%
Europe	88.3%	11.1%	0.7%	0.0%	0.0%
Indian Ocean Isl	75.8%	15.8%	8.5%	0.0%	0.0%
North America	77.4%	14.9%	7.3%	0.3%	0.0%
Pacific islands	57.2%	28.7%	13.6%	0.6%	0.0%
South America	82.0%	10.8%	6.6%	0.7%	0.0%
World	77.7%	17.0%	5.0%	0.4%	0.0%

(sources: Peduzzi et al. 2011)

Table 4-5: Trend in Floods Physical Exposure (in thousand people per year)

IPCC Region	1970	1980	1990	2000	2010	2020	2030
North America	640	720	820	930	1030	1120	1190
Central and South America	550	690	840	990	1110	1230	1320
Caribbean[1]	70	90	110	130	150	170	180
Europe	1650	1760	1850	1870	1880	1890	1870
Africa	850	1130	1480	1920	2440	3030	3640
Asia	29780	37370	46630	55750	64090	71640	77640
Australia and NZ	30	30	40	40	50	50	60
World	**33570**	**41790**	**51760**	**61620**	**70750**	**79130**	**85910**

(sources: Peduzzi et al. 2011)

Table 4-6: Trend in Floods Triggered by Precipitation Physical Exposure (in thousand people per year)

IPCC Region	1970	1980	1990	2000	2010	2020	2030
Polar	0.0	0.0	0.0	0.0	0.0	0.0	0.0
North America	2.2	2.9	3.5	4.1	4.6	5.0	5.2
South America	5.7	7.4	9.2	11.1	12.9	15.0	16.7
Islands	1.9	2.1	2.6	3.1	3.5	4.1	4.4
Europe	2.3	2.6	2.8	2.8	3.0	3.1	3.2
Africa	4.4	5.5	7.5	9.9	12.8	16.2	19.6
Asia	35.7	44.2	53.5	62.3	70.3	77.8	83.6
Australia and NZ	0.1	0.1	0.1	0.1	0.1	0.1	0.1
World	**52.3**	**64.8**	**79.0**	**93.5**	**107.3**	**121.1**	**132.9**

(sources: Peduzzi et al. 2011)

[1] Only catchment bigger than 1000 km2 are included in this analysis. So in the Caribbean, only the largest islands are covered

Table 4-7: Coastal Systems: Summary Table of Observed and Predicted Exposure Trends (see text)

Coastal systems	Current exposure	RSLR	Storm surges	Storm waves	Extreme rainfall	Sediment supply changes
Beaches	X	XX	XX	XX	x	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	X-o	XX	x	thr
Mangroves	X	XX	xx	xx	-	xx (if negative)
Coral reefs	X	-	-	XX	XX	XX (if positive)
Seagrasses	x	-	-	X	xx	x

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.

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: 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)	Descriptor 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 stress on growth and development 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 stress on growth and development 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 variability use were assumed.	Temperature (daily maximum and minimum) , radiation, CO2 concentration	Rice yield (mean and inter-annual variability)	Tokai, Chubu, Kansai regions	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 .	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 on 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 redistributing the water by melting during the dry season. The glaciers recession reduces the buffering role of the glaciers, meaning more floods during raining season and more water shortage during the dry season. Glaciers hold rocks and other debris that are exposed when glaciers retreat and could lead to debris flows after heavy rainfalls or earthquakes. Glacier recession also forms high altitude lakes and some of which may release after earthquakes, or avalanches create a GLOF.	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, and most eat all they produce, very few sell it. (e.g. only 36% of Kenyan households sell ,maize) There is an inequality of income which is likely to grow as farms get smaller due to population growth and environmental degradation Both famers and their governments have limited capacity for recovery. 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	Food shortage and loss of cash livelihood due to crop failure Crop price increase degradation 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. Global food price increases are burdened disproportionally by low-income countries, where many people spend up to 50% of their income on food. 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	The initial impact is food shortages for those entirely dependent on their own produce, and those whose livelihood depends on their crops. Crop-failure is a driver for rural-urban migration, and is expected to worsen under climate change. Since 1970 Malawi has had increased frequency and severity of droughts and floods, less seasonal rain and higher temperatures. A hybrid drought tolerant maize has been promoted, but requires expensive inputs which farmers cannot afford. After Cyclone Nargis in Myanmar converged with the global financial crisis and saw the rural economy collapse as credit was withdrawn making food security a significant concern. The factors influencing recent price increases in many ways a mirror to the challenges global food security will face in the next century under climate change. Due to changes in marine ecosystems, populations will have limited access to fish, 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.	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); (Vincent et al 2008).
Food China 2000-2007	Less awareness and inadequate 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 expanding drought areas in the past 50 years (60% of annual average disaster-related crop loss was caused by drought), and the trend is predicted to be worse in the next decade.	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 by 5-10% on average annually. Adaptive measures would lower down the vulnerability of these areas.	Wang (2002)
Food China Near- mid term future	No adaptation assumed	Temperature	Impacts on crop production		A 2.5ºC increase would cause a net decrease of Chinese crop production if without taking any adaptation measures.	Xiongwei et al, (2007)
Health	High HIV/AIDS prevalence in	Drought	Child nutritional status	Better-off (modern) area with more	Areas with higher HIV/AIDS showed more deterioration in child nutrition. A significant	Mason et la. (2005)

Health Lesotho, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe Present (2001-2003)	modern area is causing high sensitivity to drought.	Drought	(prevalence of underweight)	HIV/AIDS	area-level interaction was found for HIV/AIDS within the drought period, associated with particularly rapid deterioration in nutritional status. 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) governance 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 years old and 40+ year old females	Mortality was greatest among <10 year old children and 40+ year old females. Nearly 22% of people who did not reach a concrete or brick structure died, whereas all people who sought refuge in such structures survived.	Bern et al. (1993)
Health Ethiopia near past	Lack of flood-specific policy, absence 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 diarrhoea during and after the flood, and the risk of non-cholera diarrhoea was higher for those with lower education level and not using tap water	Hashizume et al. (2008)
Health Germany 2002		Food	Injuries and diarrhoea		In 2002 report, WHO assumed that countries with 6,000+ US dollars of per capita GDP. On the contrary, diarrhoea 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		Floods can increase the incidences of malaria. In Mozambique, the incidence of malaria increased four to five times after the flood in 2000 (compared with non-disaster periods).	Kondo et al. (2002)
Water China, Yellow River 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	-	Forest fires, drought, deforestation	Biodiversity losses, soil erosion, desiccation, GHG emissions, deforestation, cascading		Forest fires are exacerbating 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	Field et al.(2009); Van Der Werf et al.(2008); Costa and Pires (2009); D'almeida et al. (2007); Phillips

Forestry / Ecosystem The tropical forests of South America, Africa and Asia 1960 - current	-	Forest fires, drought, deforestation	hazards		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.	et al. (2009)
Forestry/ Ecosystem North America Siberia -2100	-	Temperature	Forest fire (the area affected)		In the western part of North America over the past 30 years the area affected by forest fires has increased twofold, and in the coming 100 years under expected warming it will increase by a further 80%. Modelling of forest fires in Siberia shows that temperature increases may result in the number of years with severe fires increasing twofold, area affected by forest fires increasing by almost 15% per year and timber resources reducing by 10%.	?
Forestry, tourism, ecosystems Mediterranean countries 1900-2005 (observed) and 2020-2100 modelled		Heat waves, droughts	Forest fires, lightning	Forest farming, tourism, rural settlements	Increased duration of fire season and summer temperatures. Higher coping capacity by improving meteorological prediction, better forest fire fight resources, better knowledge of combustion material	?
Forestry / Ecosystem China 1970-current	-	temperature, others	forest coverage		Insect swarms cause significant damage to China's forests. The economic loss from affected forests areas is more than 80 billion RMB annually since 1970s in China. It is also responsible for about 6% of total re-forestation in China annually.	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, the intensity and frequency of which is projected to increase. Moreover, as the size/permanence of coastal communities and infrastructure has increased significantly over recent decades, so does the exposure, and the ability of coastal systems to respond diminishes. Rapid SLR is likely to impact natural systems more severely and amplify the potential economic losses/costs of adaptation. Coastal landforms are highly likely to suffer increased rates of erosion, while coastal ecosystems, 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 and tourism. 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	The Copenhagen Diagnosis (2009); Lenton et al(2009); Cai et al.(2009); Ericson et al. (2006); Woodroffe (2008)

					permanent population evacuation. In some coastal settings and landforms, SLR will be further exacerbated by (i) land subsidence triggered by natural processes and/or human-induced interference; (ii) diminishing sediment supply.	
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 A 40 to 80cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost. Changes in permafrost damages the foundations of buildings and disrupts the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10 to 12% in 20 to 25 years, with permafrost borders moving 150 to 200 km northeast.	Sherstyukov (2009); Anisimov et al. (2004)
Infrastructure / Settlements Japan 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 landslides (Tochigi, Gumma, Saitama, Toyama, Ishikawa, Fukui, Hiroshima, Kagoshima).	Slope failure risk is expected to increase in future in many places, as a result of increasing frequency/intensity of strong rainfall. Slope failure risk in Japan under the changed precipitation rate was evaluated for a period around 2050. Using spatial data on daily precipitation, geography, geology, and land use, slope failure probability was calculated Areas with high slope failure risk is predicted in mountainous areas. Particularly, in the South Hokkaido region, the coast of the Japan Sea from Hokuriku region to Chugoku region, and median tectonic zone from Tokai region through to the Shikoku region. In some prefectures (Tochigi, Gumma, Saitama, Toyaam, Ishikawa, Fukui, Hiroshima, and Kagoshima), the expected economic loss due to slope failure is highertherefore, 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. Sanitation infrastructure is the main determinant of the contamination of urban floodwater with faecal material, presenting a substantial threat of enteric disease.	Flooding (also leading to disease), landslides and heatwaves. It is well documented that, in most cities, the urban poor live in the most hazardous urban environments. . Worldwide, about one billion live in informal settlements, and this proportion is growing at		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	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. Poorer groups get hit hardest by a combination of; greater exposure to hazards (with no or limited hazard-removing infrastructure), high vulnerability (due to makeshift housing), less capacity to cope (due to a lack of assets, insurance, and marginal livelihoods), less	Ahern et al.(2005); Douglas et al.l (2008); Hardoy et al.(2001); Kovats and Akhtar (2008); Revi (2008); UNECE (2009); Hardoy, Mitlin and Satterthwaite, (2001); UN/POP/EGM-URB/2008/16;

Settlements/other Global Current – short term	.In Andhra Pradesh, India, a heat wave killed more than 1,000 people – mostly labourers working outside in high temperatures in smaller urban settlements.	about twice the rate of formal settlements.		floodwaters. Those who work outside without heat protection are also very vulnerable.	state support and limited legal protection. Low-income groups also have far less scope to move to less dangerous sites. Informal settlements are found in all regions, for example there are some 50 million people in such areas in Europe.	Ahern et al.(2005); Douglas et al.l (2008); Hardoy et al.(2001); Kovats and Akhtar (2008); Revi (2008); UNECE (2009); Hardoy, Mitlin and Satterthwaite, (2001); UN/POP/EGM-URB/2008/16;
Energy Iberian Peninsula, Mediterranean regions 1920–2000	Hydroelectric production represents, in an average year of precipitation, 20% of the total Spanish electricity production and 35% of 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 the 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.	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. 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		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.	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%. In the Caribbean, reduced tourist amenity as beaches erode with sea level rise, and degraded snorkelling and scuba activities due to coral bleaching. 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. 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. 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	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 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 the 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.	become more attractive in summer. Tourist seasons in different areas are expected to shift, with some areas gaining while others lose.		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.	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 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 tourists, 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 in travelling and holidays during transition seasons (spring and autumn)	Perry (2003); Esteban Talaya et al. (2005)
Tourism World, regional Near term	-	Climatic 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		An increase in warmer days in Europe would lead to the increase in summer holiday spots as Northern countries would be more attractive, however this would close the gap with the currently popular Southern 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	-	Hurricanes, typhoons, and windstorms are some of the most costly extreme evernts 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.	ABI (2005)

Economy Indonesia Current	-	flooding	Food shortage, water and soon	Economic sectors, health, community	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 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	employment, health, livelihood, working of women	gender equality	Poor women and children are among the most vulnerable to climate change effects, they may also exacerbate gender inequalities, create extra work for women and increase 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 4-11: 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 (2.5ºC)	A2: HadAM3h (3.9ºC)	B2: ECHAM4 (4.1ºC)	A2: ECHAM4 (5,4ºC)	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 4-12: 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 - Possible return of diseases (e.g. malaria) - 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 - Shorter ski season in Alps - Higher-lying winter sports resorts may escape adverse snow conditions	- Longer summer season - Heat waves to increase in countries not adapted to high temperatures - Summer floods in central European rivers and southern UK - Less snow in low elevation ski resorts in 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%), Finland (8%), ?(15%), ?(13%)	- 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 least until 2050s)	- Extended summer season - Winter snow conditions may be deteriorated at low altitudes but improved during winter due to increased snow precipitation amount.
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	- None effect of temperature rise - Major impacts from weather extremes in high vulnerable economies	- Tropical storms to increase - Water shortage - Coastal erosion by storms - Coral bleaching - Loss of biodiversity

	Republic (14%), Jamaica (33%), Bahamas (51%)	- Increasing incidence of vector-borne diseases	
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%), Argentina (6%), Brazil (5%)	- Tours to landscape and cultural factors (Maya ruins, Machu Picchu) slight climate dependence - Rising temperatures and natural disaster to affect negatively in tourist comfort at seaside resorts. - Increasing incidence of vector-borne diseases	- Rising temperatures and heat waves. - Droughts and water shortage - More intense tropical storms to cause damage of infrastructures
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-dependent country - Increasing incidence of vector-borne diseases	- 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.
Australia/ Oceania	- Tourism slightly dependent on climate - Contribution of GDP Australia (11%), New	- City tourism non-sensitive to climate impacts - Australian outback tourism to seasonal readjusts to avoid	- Coral bleaching to affect attrativeness of the Great Barrier Reef - Queensland region subject to

	Zealand (11%), Pacific Islands	high temperatures - Australia: Tourism activity to be centered during austral winter - Adventure holidays and green holidays to benefit in New Zealand	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 4-13: 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 4-14: 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 4-15: 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 4-16: Climate Related Disaster Occurrence and Regional Average Impacts from 2000-2008 (Sources: Vos et al., 2010)

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*

Table 4-17: Estimated Change in Disaster Losses in 2040 Under Projected Climate Change and Exposure Change, Relative to the Year 2000 from Twenty-One Impact Studies, Including Median Estimates per type of Weather Hazard (Sources: Bouwer, 2010)

A. Impact of projected climate change						
Study	Hazard type	Region	Estimated loss change [%] in 2040			
			Min	Max	Mean	Median
Pielke 2007b	Tropical storm	Atlantic	58	1365	417	30
Nordhaus 2010	Tropical storm	USA	12	92	47	
Narita et al. 2009	Tropical storm	Global	23	130	46	
Hallegatte 2007	Tropical storm	USA	-	-	22	
ABI 2005a; 2005b	Tropical storm	USA, Caribbean	19	46	32	
ABI 2005a; 2005b	Tropical storm	Japan	20	45	30	
ABI 2009	Tropical storm	China	9	19	14	
Schmidt et al. 2009	Tropical storm	USA	-	-	9	
Bender et al. 2010	Tropical storm	USA	-27	36	14	
Narita et al. 2010	Extra-tropical storm	High latitude	-11	62	22	15
Schwierz et al. 2010	Extra-tropical storm	Europe	6	25	16	
Leckebusch et al. 2007	Extra-tropical storm	UK, Germany	-6	32	11	
ABI 2005a; 2005b	Extra-tropical storm	Europe	-	-	14	
ABI 2009	Extra-tropical storm	UK	-33	67	15	
Dorland et al. 1999	Extra-tropical storm	Netherlands	80	160	120	
Bouwer et al. 2010	River flooding	Netherlands	46	201	124	65
Feyen et al. 2009	River flooding	Europe	-	-	83	
ABI 2009	River flooding	UK	3	11	7	
Feyen et al. 2009	River flooding	Spain (Madrid)	-	-	36	
Schreider et al. 2000	Local flooding	Australia	67	514	361	
Hoes 2007	Local flooding	Netherlands	16	70	47	
B. Impact of projected exposure change						
Study	**Hazard type**	**Region**	**Estimated loss change [%] in 2040**			
			Min	**Max**	**Mean**	**Median**
Pielke 2007b	Tropical storm	Atlantic	164	545	355	172
Schmidt et al. 2009	Tropical storm	USA	-	-	240	
Dorland et al. 1999	Extra-tropical storm	Netherlands	12	93	50	
Bouwer et al. 2010	River flooding	Netherlands	35	172	104	
Feyen et al. 2009	River flooding	Spain (Mad)	-	-	349	
Hoes 2007	Local flooding	Netherlands	-4	72	29	

Table 4-18: Estimates of global costs of adaptation

Study	Results (billion USD/a)	Time frame	Sectors	Methodology and comment
World Bank, 2006	9-41	Present	Unspecified	Cost of climate proofing foreign direct investments (FDI), gross domestic investments (GDI) and Official Development Assistance (ODA)
Stern, 2006	4-37	Present	Unspecified	Update of World Bank (2006)
Oxfam, 2007	>50	Present	Unspecified	WB (2006) plus extrapolation of cost estimates from national adaptation plans (NAPAs) and NGO projects.
UNDP, 2007	86-109	2015	Unspecified	WB (2006) plus costing of targets for adapting poverty reduction programmes and strengthening disaster response systems
UNFCCC, 2007	28-67	2030	Agriculture, forestry and fisheries; water supply; human health; coastal zones; infrastructure	Planned investment and Financial Flows required for the international community
World Bank, 2010	70-100	2050	Agriculture, forestry and fisheries; water supply; human health; coastal zones; infrastructure	Improvement upon UNFCCC (2007): more precise unit cost, inclusion of cost of maintenance and port upgrading, risks from sea-level rise and storm surges.

Table 4-19: Regionalized Annual Costs of Adaptation for Wet and Dry Scenarios

EAST ASIA AND PACIFIC WILL SHOULDER THE BIGGEST BURDEN

(Global costs of adaptation by region)

Aggregation type/ Scenario	East Asia & Pacific	Europe & Centr.Asia	Latin America & Caribbean	Middle East/ North Africa	South Asia	Sub-Saharan Africa	Total
Gross-sum/ Wet Scenario	25.7	12.6	21.3	3.6	17.1	17.1	97.5
X-sum/ Dry Scenario	17.9	6.9	14.8	2.5	15	14.1	71.2

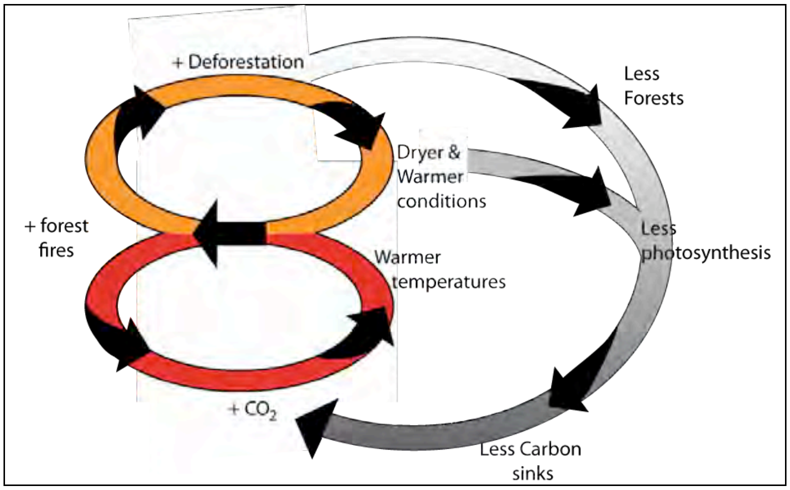

Figure 4-1: Simplified Diagram of the Positive Feedbacks between Drought, Forest Fires and Climate Change

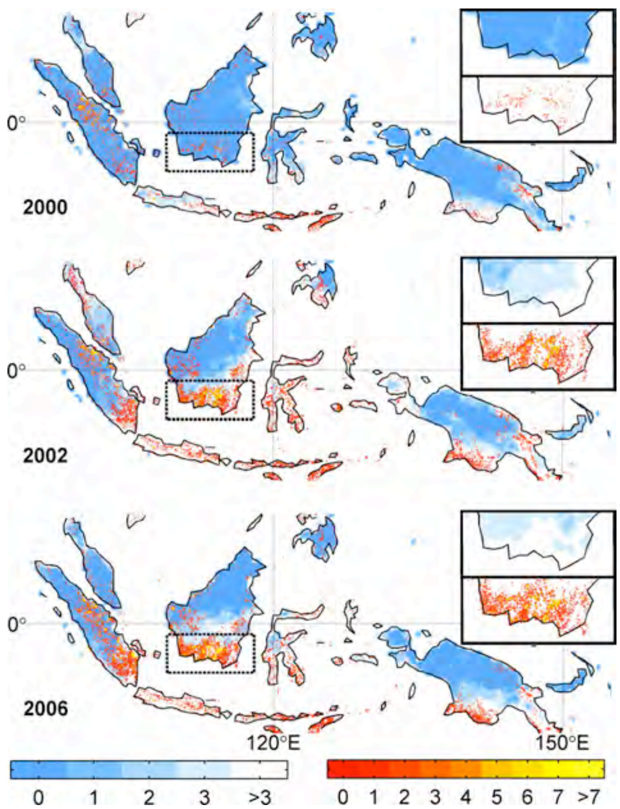

Figure 4-2: Dry Season Length and Fire Detections for the Strong 2000 La Niña and 2002 and 2006 Moderate El Niño Years

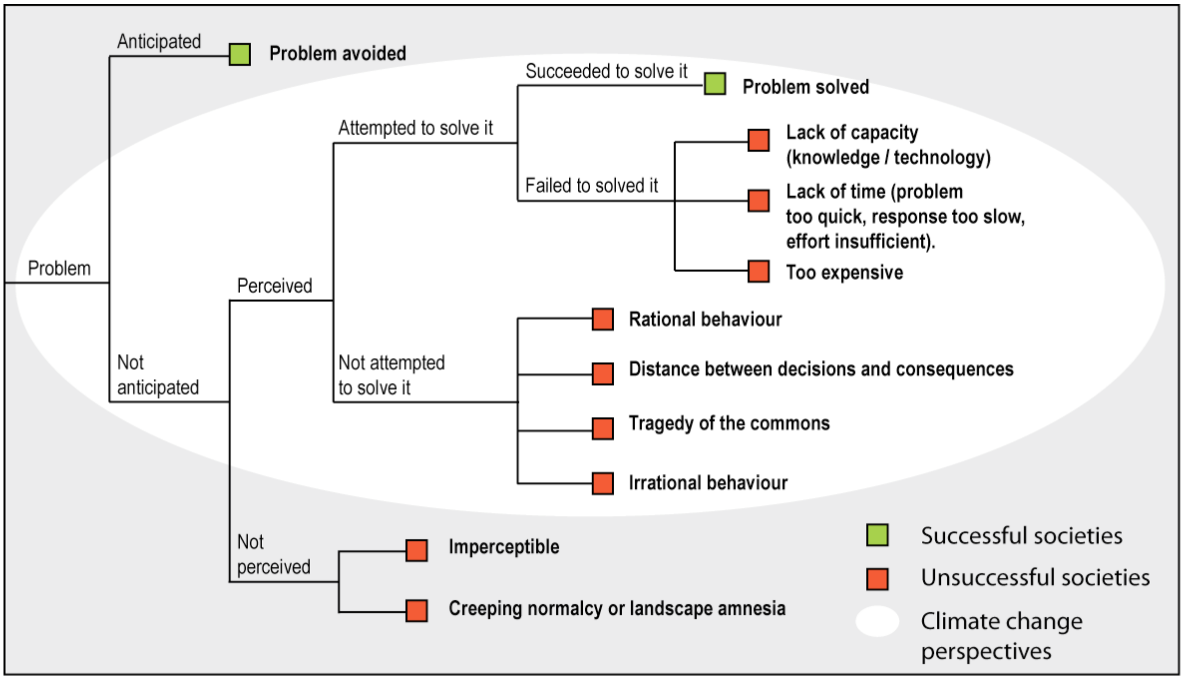

Figure 4-3: Path for Successful Problem Solving In Past Societies
Climate change share many aspects with unsolved issues (white area).

Figure 4-4: The Total Economic Losses and Insured Losses from "Great Weather Related Disasters" Worldwide (1950-2010, adjusted to present values)

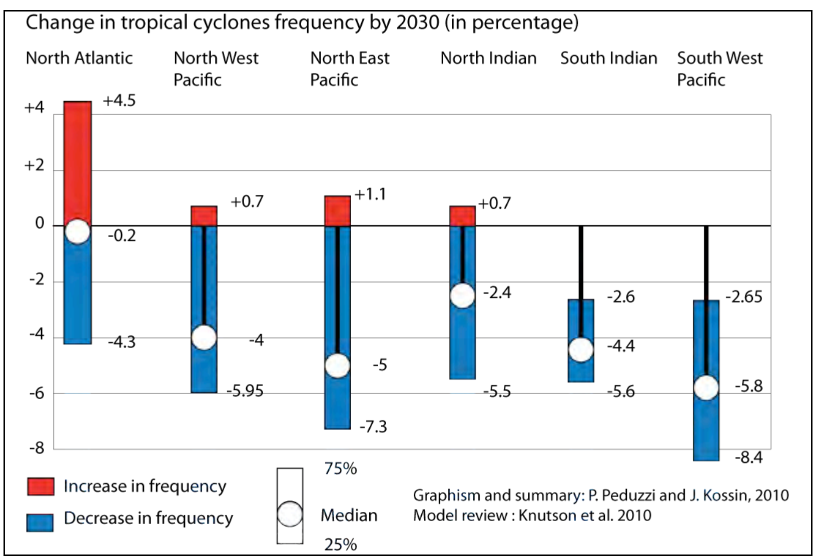

Figure 4-5: Forecast Changes in Tropical Cyclones Hazards Frequencies by 2030 (Source: Peduzzi et al. 2011; Review of Models Based on Knustson et al. 2010)

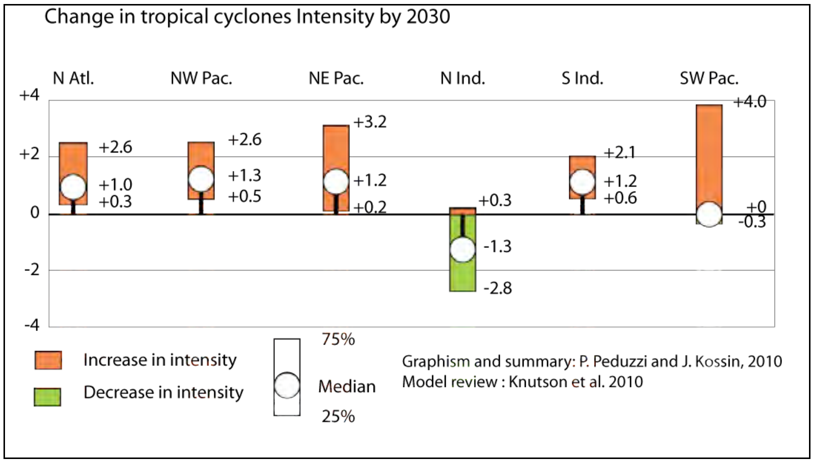

Figure 4-6: Forecast Changes In Tropical Cyclones Hazard Intensities by 2030 (Source: Peduzzi et al. 2011; Review of Models Based on Knustson et al. 2010)

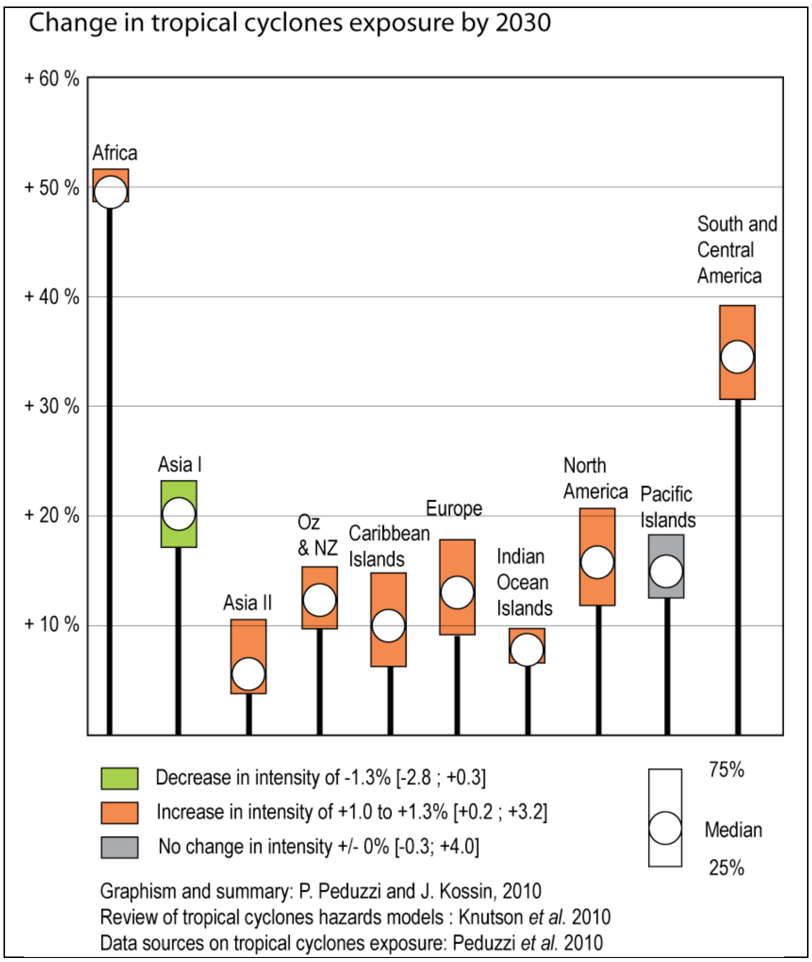

Figure 4-7: Forecast Changes in Tropical Cyclones Population Exposure (Source: Peduzzi et al. 2011)

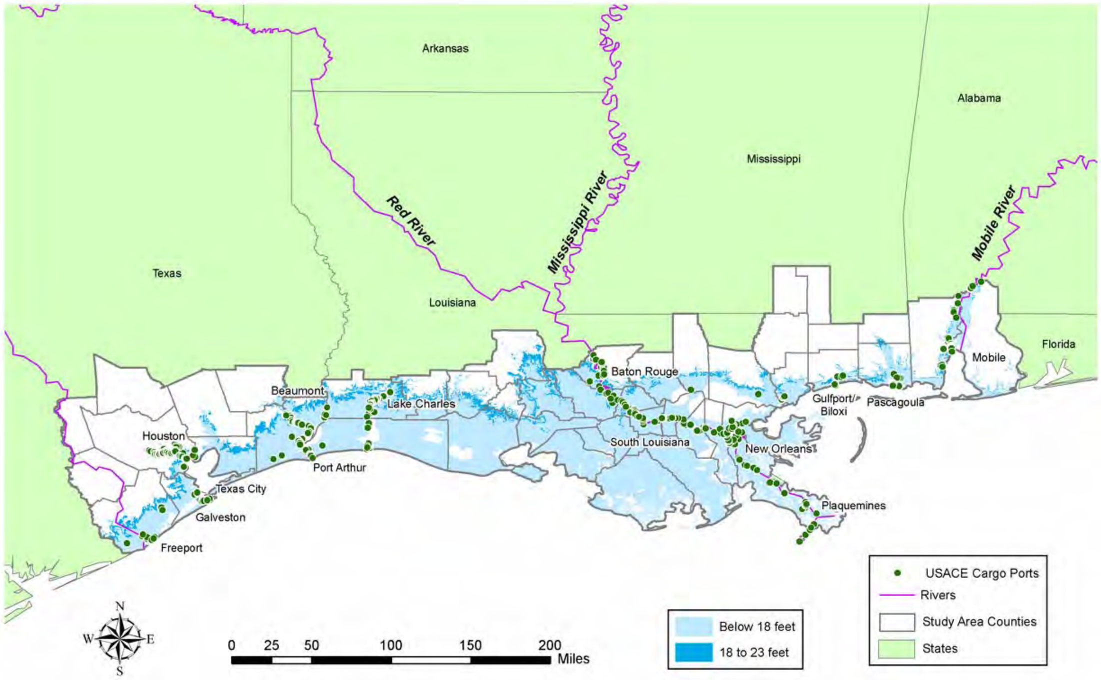

Figure 4-8: Freight Handling Port Facilities at Risk from Storm Surge of 5.5 and 7.0m in The US Gulf Coast (Source: CCSP, 2008)

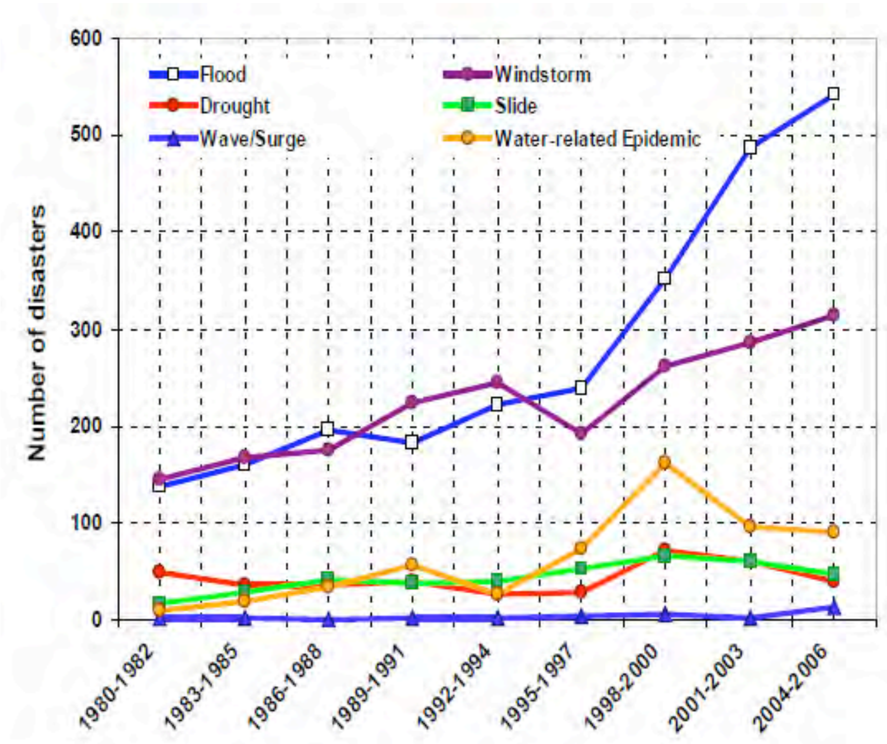

Figure 4-9: Water-Related Disaster Events Recorded Globally, 1980 to 2006 (Source: Adikari and Yoshitani, 2009)

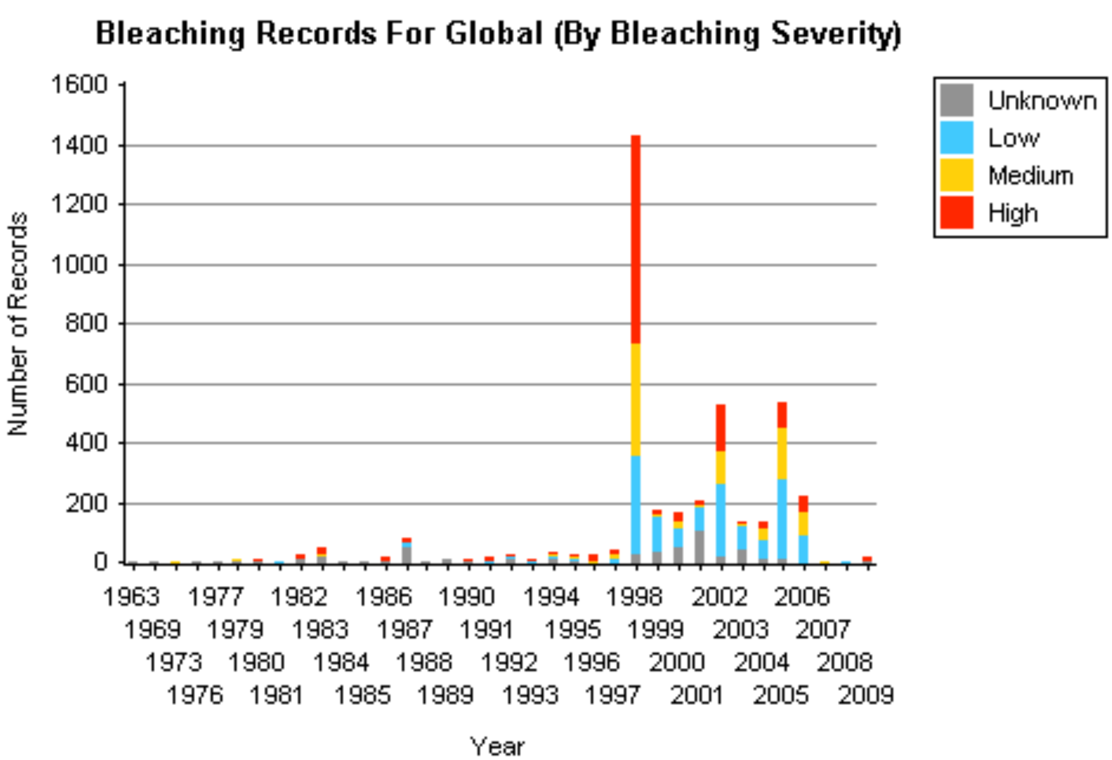

Figure 4-10: Coral Bleaching Record

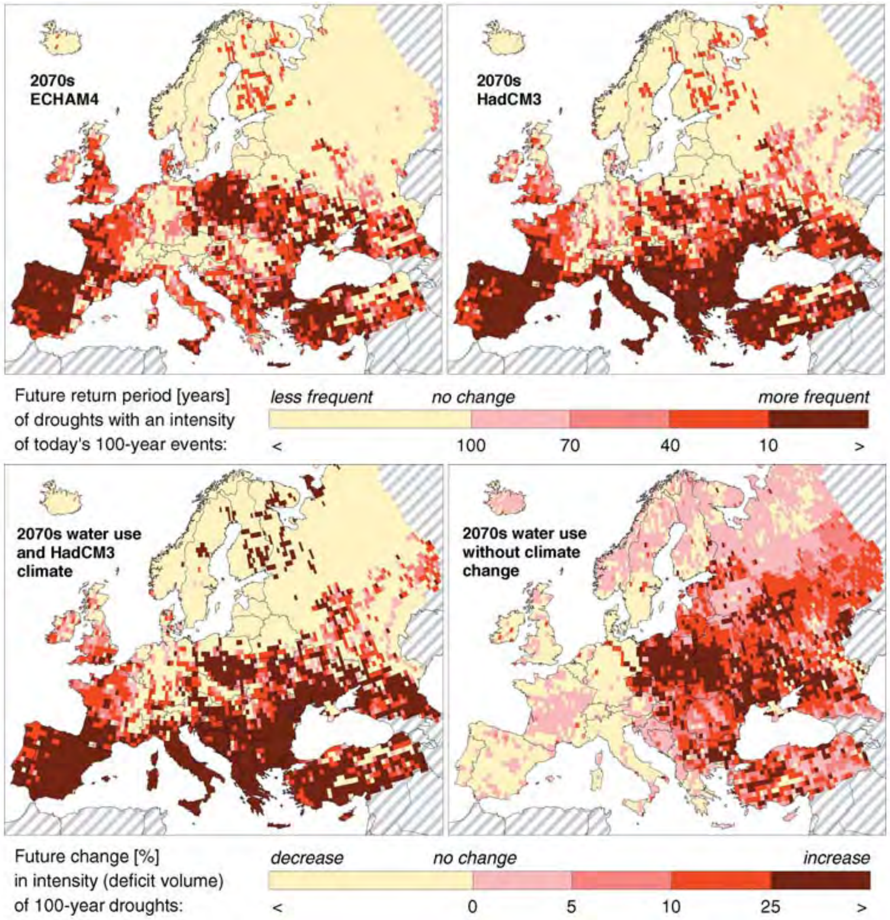

Figure 4-11: Change in Indicators of Water Resources Drought across Europe by the 2070s (Source: Lehner et al., 2006).
A (top): change in the return period of the current 100-year drought deficit volume, with change in river flows and withdrawals under two climate scenarios
B (bottom): change in the intensity (deficit volume) of the 100-year drought with changing withdrawals, with climate change (left, with the HadCM3 scenario) and without climate change (right)

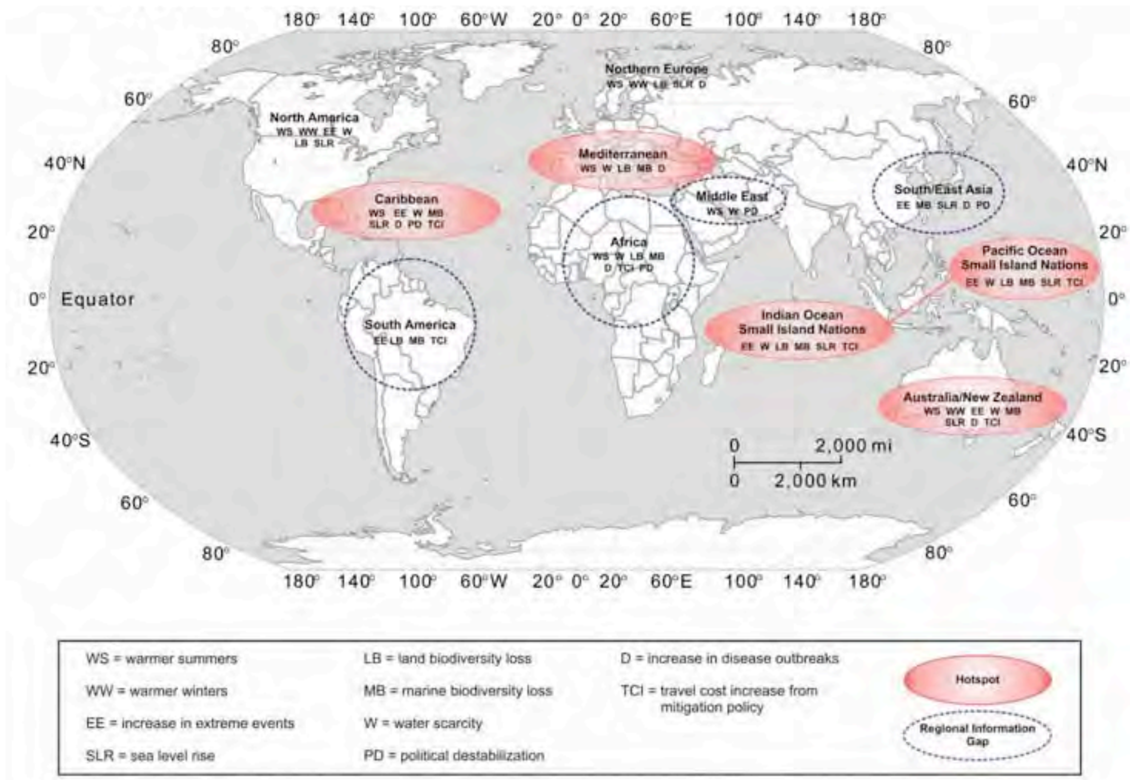

Figure 4-12: Climate Change Vulnerability Hotspots in the Tourism Sector (Source: Scott et al., 2008)

Figure 4-13: People Affected by Natural Disasters from 1971-2001 [Updated Figure on climatic disasters needed]

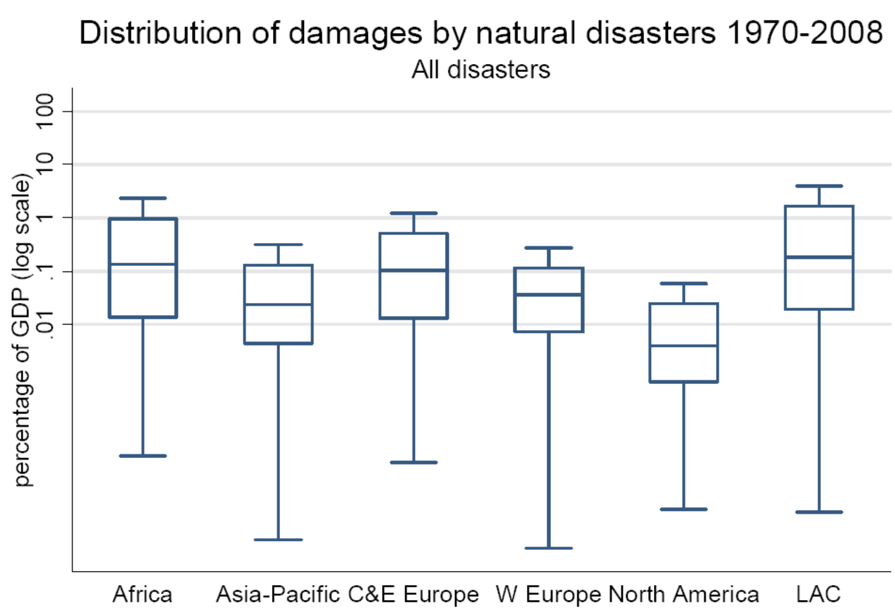

Figure 4-14: Distribution of Regional Damages as a % of GDP (1970-2008) (Source: EM-DAT, WDI database, calculated by Cavallo and Noy, 2009)

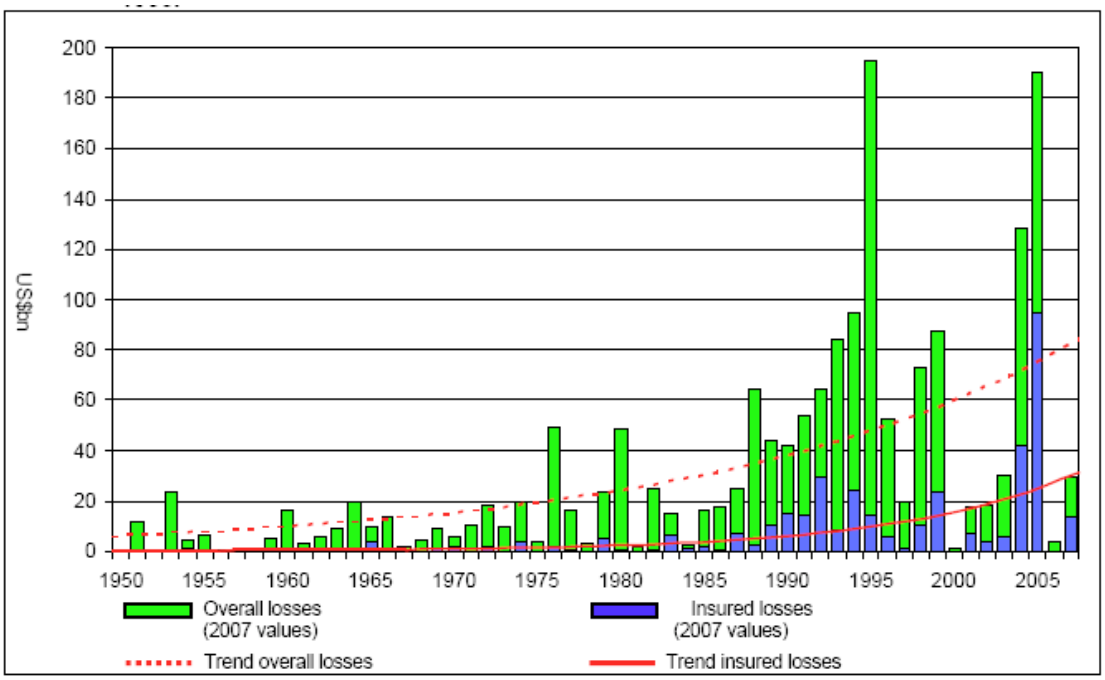

Figure 4-15: The Overall Losses and Insured Losses from Natural Disasters Worldwide (adjusted to present values) (Source: Munich-Re, 2007)

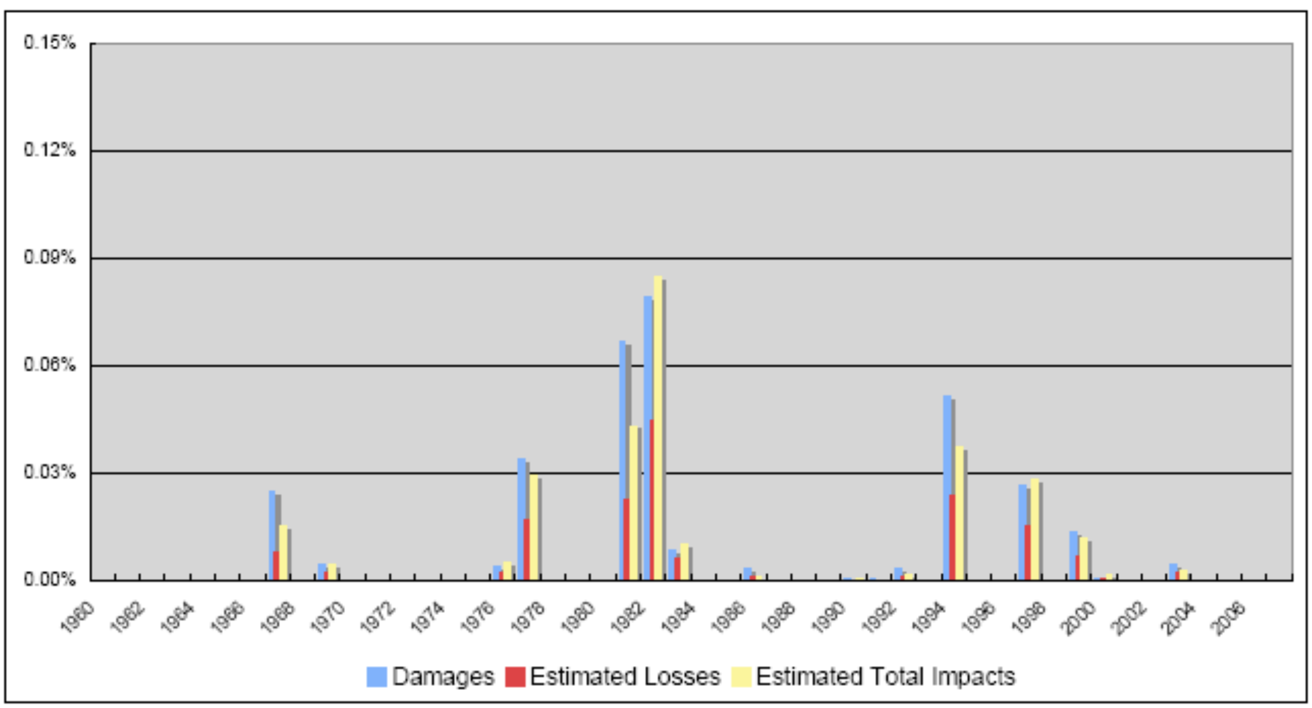

Figure 4-16: Historical Trends of Climatological Disasters (normalized)

Chapter 5. Managing the Risks from Climate Extremes at the Local Level

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Contents

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. Disasters are most acutely experienced at the local level and coping strategies to deal with disasters 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 management in the context of climate change will need to be tailored to local conditions and experiences by integrating local knowledge and supporting local empowerment and collective action.** [5.1, 5.3]

There are two key principles in disaster risk management applicable to climate change adaptation at the local level: **1) mainstreaming disaster risk management into policies and practices, addressing social welfare, quality of life, infrastructure, and livelihoods, and 2) incorporating a multi-hazards approach into planning and action.** [5.2, 5.4, 5.5.3]

There is a strong and complex link between local livelihood security and extreme and non-extreme natural hazard events. While localities with secure and sustainable livelihoods are likely to have better coping capacity for climate change and changing patterns of climatic vulnerability, climate sensitive events may also undermine local sustainability and thus increase vulnerability. **Building sustainable livelihoods is an important adaptation to climate change at the local level.** [5.4.1]

Local adaptation to climate change is not a finite set of actions, but an on-going process that includes learning, changing scenarios, and changing development pressures and opportunities. The localized expression of the type, frequency, and extremeness of climate-sensitive hazards will be set within these national and international contexts. **The main challenge for local adaptation to climate extremes is to find a good balance of measures that simultaneously address fundamental issues related to the local enhancement of local collective actions, and the creation of subsidiary structures at national and international scales that complement such local actions.** [5.4, 5.5, 5.6]

The costs and non-economic losses of disasters at the local level are difficult to estimate. Similarly, the identification of climate change impacts at the local level is complicated. Accordingly, estimating the costs of disasters and adapting to changes in climate extremes is also difficult to estimate. **There is a need for further development of databases and tools to enable such costs and non-economic losses to be assessed from the bottom up perspective at the local level.** [5.4.2, 5.5.1, 5.6]

5.1. Introduction

5.1.1. Chapeau

The United Nations Framework Convention on Climate Change recognizes the management of the global climate system as a "common but differentiated responsibility." The assessment of the existing knowledge and practice about the way in which the common responsibility is shared in this special report is approached through the perspective of scale and the division into local, national, and global. Approaching the issue from the perspective of scale suggests two important considerations. What is the appropriate distribution of responsibility for the management of risks from climate extremes? Is the present local, national, international allocation working satisfactorily or are there options or choices that might improve upon existing management?

The pattern of responsibilities as assessed in this chapter and those that follow, Chapter 6 (national), and Chapter 7 (international), is complex. Local decisions are embedded in national governance structures, while international arrangements can affect national disaster risk management (Figure 5.1). These complex linkages between local, national, global have evolved over time as the nature and magnitude of the risks has changed; as the capabilities of the various levels of institutions and stakeholders have changed; and as the international architecture on climate change and disaster risk have evolved over the past two decades. There is a primary focus on risk management as a governmental function, especially at the national and international scales. 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 often is blurred, and this is equally considered in these chapters.

[INSERT FIGURE 5-1 HERE:
Figure 5-1 Linking local to global actors and responsibilities.]

The division into separate chapters on local, national, and global recognizes both the bottom-up and the top-down strategies for managing risks and opportunities for climate change adaptation as well as the diversity of stakeholders engaged in the process. In the assessment of the science and practice for managing the risks from climate extremes as manifested at these different scales, local to global, it is possible to discern some guiding principles and assumptions (Box 5.1), which permeate each chapter and provide the continuity between them.

_____START BOX 5-1 HERE_____

Box 5-1. Principles of Shared Responsibility for Managing Risks from Climate Extremes

The following "Principles" provide the substantive content of Chapters 5, 6, and 7 (separately and as a group). They exemplify in varying ways the application of these ideas chiefly at local, national, and international scales and at the end of Chapter 7, how integration across scale is addressed.

1. *Subsidiarity*. The principle of subsidiarity is based on the ideas that the functions of government should be carried out at the lowest practical level. It ensures that government decisions are made as closely as possible to the people immediately affected. It strengthens accountability and reduces the dangers of making decisions in places remote from their point of application. In the case of risk management of climate extremes it is clear that major atmospheric events such as tropical cyclones, large floods and droughts can quickly overwhelm the capacity of local governments to cope, and in some instances even national governments. The principle of subsidiarity does not limit

or constrain the action of higher orders of government. It merely counsels against the unnecessary assumption of responsibilities at a higher level.

2. *Social Contract-Shared Responsibility*. When the management or coping capacity of lower levels of government such as communities, are exceeded then higher levels can be involved on the basis of a formal or informal social contract. Our common humanity leads people to care for each other especially in times of adversity. National governments come to the aid of communities and other sub-national entities. Nations cooperate and help each other when their individual capacities are stretched or exceeded. At the global level multilateral agreements are created to help in the identification, planning, and execution of models of mutual assistances, and in some cases the reallocation of responsibilities.

3. *Systemic Risks*. Often the impacts of climate extreme-related impacts potentially extend beyond localities and national boundaries. Regions including groups of several countries may be directly affected by tropical cyclones or droughts. Impacts of a less direct kind may extend well beyond the immediate locality or region affected. Relationships and connections involving the movement of goods (trade), people (displaced populations), and finance (capital flows and remittances), can extend to continents and indeed to the world as a whole.

4. *Economic efficiency*. Local to global risk management can be shown to be economically efficient. Greater aggregate benefits can be achieved through cooperation than when communities or countries are left to cope by themselves.

5. *Legal obligations*. Increasingly the allocation of roles and responsibilities among levels of government is codified into law. At the local and national level s this is often mandatory and provided for in legislation, regulations, ordinances. At the international level, “obligations” are sometimes termed “soft law”, where there is an agreement on expected behavior, but no penalties or sanctions are applied in the case of non-compliance.

6. *Reflexivity*. How actions at one level affect all others. These actions can both enhance or constrain coping and risk management. For example, actions taken at one level (e.g. local) can benefit coping and risk management at the national level. At the same time, national and international actions may constrain coping and risk management at the local level.

7. *Development*. Disasters are viewed from a developmental perspective, revealed by the deeply rooted patterns of vulnerability that have led to unsafe conditions. The impact of devastating floods and cyclones has set back generations of development investments in local and national economies, infrastructure, and human habitats. Instead of providing one-time relief after every event thereby creating a culture of dependence, development perspectives highlight opportunities for genuine social, economic, and physical development post-event.

_____END BOX 5-1 HERE_____

5.1.2. Definitions and Concepts Used

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, local refers to a range of places, management structures, institutions, social groupings, conditions, and sets of experiences and knowledge that exist at a scale below the national level. Local includes the set of institutions (public and private) that maintain and protect social relations as well as those that have some administrative control over space and resources where choices and actions for disaster risk management and adaptation to climate extremes are initially independent of national interventions. Local includes indigenous knowledge about disaster risk and grass roots actions to manage it. Local also includes functional or physical units such as watersheds, ecological zones, or economic regions and the private and public institutions that govern their use and management. Each of the differing connotations of local means there are differing approaches and contents of disaster risk management practice, differing stakeholders and interest groups, and more significantly differing relations to the national and international levels (Thomalla *et al*., 2006).

Locales can range from villages, districts, suburbs, cities, metropolitan areas, through to regions. They vary in their disaster experience, who and what is at risk, the potential geographical extent of the likely impact and responses, and in stakeholders and decision-makers. Localities and the people who live there have considerable experience with short-term coping responses and adjustments to disaster risk (UNISDR, 2004), as well as with longer-term adjustments such as the establishment of local flood defenses or the selection of drought resistant crops. 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, localities have developed extensive reactive disaster risk management practices. However, disaster risk management also entails the day to day struggle to improve livelihoods, social services, and environmental services. Local 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.

5.1.3. Local Climate Extremes

Local communities routinely experience natural hazards many from climate-related events (see Chapter 3). Drought has affected localities from Africa to the Americas, to Australia and New Zealand. Tropical and extra-tropical windstorms are seasonal events for many regions. Flooding and windstorms (cyclones and hurricanes) are among the most prevalent, with the impacts measured in economic losses as well as human losses (IFRC, International Federation of Red Cross and Red Crescent Societies, 2010). However, local places 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 and southern hemispheres (Alcamo *et al*., 2007; Field *et al*., 2007). More intense rainfall has been observed and is projected for many parts of the world (see Chapter 3), possibly influencing flooding and mudslide occurrences in these areas. Localities 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 some localities are experiencing certain types of hazards for the first time. 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), was the region's first local experience with a hurricane. Research demonstrates that disaster experience influences proactive behaviors in preparing for and responding to subsequent events (see section 5.3.1).

5.1.4. Basic Development and Human Security

Future changes in climate trends and patterns will alter the frequency and/or intensity of many severe climatic events (See chapter 3), especially at the local level. It is at the local level where ecosystems and communities are already facing multiple risks, where these climate sensitive hazards are first felt, and where human security is threatened. Rural communities in LDCs face greater risks of livelihood loss resulting from likely increased 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). For example, in some African countries where recurrent floods are closely linked with El Niño-Southern Oscillation (ENSO) events resulting in major economic and human losses such as Mozambique (Mirza, 2003; Obasi, 2005) and Somalia (Kabat *et al*., 2002). For such poor communities, with less developed infrastructure and health services the impacts of floods are often further exacerbated by health problems associated with water scarcity and quality, such as malnutrition, diarrhea, cholera and malaria (Kabat *et al*., 2002).

It is increasingly recognized that adaptation and disaster risk management should be integral components of development planning and implementation, to increase sustainability (Thomalla *et al.*, 2006). In other words, both 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). To effectively reduce vulnerabilities to hazards associated with climate change, coordination across different levels and sectors is required, in addition to the involvement of a broad range of stakeholders beginning at the local level (Davies, 2009; Devereux and Coll-Black, 2007; DFID, 2006; UNISDR, 2004).

Linking climate change and conflict is controversial. The conceptual debate links climate change to resource scarcity (or those essential resources to support livelihoods), which in turn leads to human insecurity. At the local scale, there are two distinct outcomes: armed conflict or migration, the latter which can also lead to increased conflict in the receiving locality (Barnett and Adger, 2007; Nordås and Gleditsch, 2007). For example environmental stresses feed the tensions between localities as they compete for land to support their livelihoods (Barnett, 2003; Kates, 2000; Osman-Elasha and El Sanjak, 2009). Extreme events such as droughts and heat waves could increase these tensions in areas already facing situations of water scarcity and environmental degradation, giving rise to conflicts and result in dislocation of large numbers of refugees and internally displaced people (IDPs). However, there is mixed evidence to support the link between climate change and violent conflict, especially in Africa (Buhaug, 2010; Burke *et al.*, 2009). While the causal chain suggested in the literature (climate change increases the risk of violent conflict) has found currency within the policy community, it has not been adequately substantiated in the scientific literature. Where such empirical studies exist, they are methodologically flawed in a number of ways: not controlling for population size; focusing only on conflict cases; using aggregated, not disaggregated climate data at sub-national scales; and having inherent inconsistencies in the timeframes used (short-term variability in violent conflict; longer term variability in climate). More research on the local climate-conflict nexus is warranted in order to demonstrate the causal linkages.

5.1.5. Context

Differences in the effects of disasters among countries are usually demonstrated using data at the national scale (e.g., EM-Dat; IFRC), yet the differential effects are experienced at the local level, and many measures to reduce disaster risk are also applied at this scale. 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 5-2). However, given the wide differences between and within developing and developed countries it is clear that single solutions for risk reduction are unlikely. Moreover, it is possible that the a history of resource exploitation, globalization, and the processes of development as currently practiced, may be increasing, rather than reducing disaster vulnerability at the local level (see Chapter 2). Those choosing strategies for reducing disaster risk and adapting to climate change, especially in developing countries need to take these processes into account (UNISDR, 2009). 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.

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Box 5-2. Capturing Local Knowledge: The Use of 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. IPCC assessment reports and other similar assessments produced by the World Bank or the International Strategy for Disaster Reduction (IRDR) represent special cases, undergoing a level of peer and public review far more extensive and rigorous than any journal publication.

Practitioner experience and local knowledge are key components in understanding disaster risk management and climate change adaptation at the local level. Utilizing the grey literature permits the understanding of the approach and the state-of-the-art of the real decision-making process, starting with the use of language and the identification of needs and solutions from the local perspective. 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.

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Strengthening coordination between climate change adaptation and disaster risk management locally will help improve the implementation— such as when, the appropriate level of coordination, and who should take the lead in the process (Mitchell and Van Aalst, 2008). Such coordination is also needed in order to avoid any negative impacts across different sectors or scales that could potentially result from fragmented adaption and development plans. This is evident in the implementation of some of the adaptation strategies, such as large-scale agriculture, irrigation and hydroelectric development, which may benefit large groups or the national interests but they may also harm local, indigenous and poor populations (Kates, 2000). It is therefore, essential that any new disaster reduction or climate change adaptation strategies must be built on strengthening local actors and enhancing their livelihoods (Osman-Elasha, 2006a). Moreover, key aspects of planning for adaptation at local level is the identification of the differentiated social impacts of climate change based on gender, age, disability, ethnicity, geographical location, livelihood, and migrant status (Tanner and Mitchell, 2008). Emphasis needs to be given to identifying the adaptation measures that favor the most vulnerable groups, and to address their urgent needs using a more coordinated and integrated management approach with the involvement of different stakeholder groups, (Sperling and Szekely, 2005). This approach may assist in avoiding mal-adaptation across sectors or scales and provide for win-win solutions.

5.2. How Local Places Currently Cope with Disaster Risk

Localities everywhere have developed skills, knowledge and management systems that enable them to interact with their environment. Often these interactions are beneficial and provide the livelihoods that people living in local places 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 (see Chapter 3), other environmental, social, political, or economic processes (many of them also global in scale) are affecting the abilities of communities to cope with disaster risks and climate-sensitive hazards (Adger and Brown, 2009; Wisner *et al*., 2004). 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.

5.2.1. Structural Measures

Structural interventions to reduce the effects of extreme events often refer to engineering works to provide protection from flooding such as dykes, embankments, seawalls, river channel modification, flood gates, and reservoirs. However, they may also include measures that strengthen buildings (during construction and retrofitting), those that enhance water collection in drought-prone areas (e.g. roof catchments, water tanks, wells), and those that reduce the effects of heat waves (e.g. insulation and cooling systems). Although many of these structural interventions can achieve success in reducing disaster impacts, they can also fail due to lack of maintenance, age, or due to extreme events that exceed the engineering design level (Doyle *et al*., 2008; Galloway, 2007; Galloway *et al*., 2009). Most structural measures have a specific design life at the time of construction and thus can be viewed more as short-term solutions with short-term benefits, which may or may not be sustainable in the longer term or under changing conditions including climate. Furthermore, technical considerations should not preclude local social, cultural, and environmental considerations (Opperman *et al*., 2009; WMO, 2003). Implementing structural measures from planning through implementation that involve participatory approaches with local residents who are proactively involved often leads to increased local ownership and 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 knowledge (ActionAid, 2005; Prabhakar, S. V. R. K. *et al*., 2009) (see also section 5.3.6). 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; Galloway, 2009). Technological responses alone may also have unintended geomorphologic and social consequences including increasing flood hazard in downstream locations, increasing costs of long-term flood protection works or increasing coastal erosion in areas deprived of sediments by coastal protection works (Adger *et al*., 2005; Hudson *et al*., 2008)(Box 5-3).

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Box 5-3. Large Dams in Brazil: Scalar Challenges to Climate Adaptation

Effective climate adaptation requires consideration of cross-scale management concerns. Any project or impact that crosses jurisdictions from local to regional to national to transnational is best planned using a trans-scalar lens (Adger *et al*., 2005). Examples are the planned or built large dams in Amazonia, Brazil (McCormick, 2011) exemplify these issues. These dams are related to water management and would cross local, regional, and national boundaries. At the national level, these dams would provide large-scale energy needs and serve major urban centers and industrial sectors across the country. At the regional level, the large Amazonian dams could bother generate energy and assist in drought management through storage of hydrological resources (Postel *et al*., 1996). Because of the expansive range and impacts of large dams, their planning and management raises a variety of scalar concerns about climate adaptation. While on one level a dam may present benefits regionally and nationally, it may also cause serious environmental and social problems locally (McCormick, 2009).

While there are many environmental benefits of hydroelectric power and large-scale water management, the uncertainty of climate change could alter such benefits at local to global scales and influence the social and environmental ramifications of these projects. For example, the flooding caused by the construction of reservoirs results in migration of locally affected communities, thereby increasing community fragmentation, poverty and ill health of humans and biota (Kingsford, 2000). This becomes a local and regional impact of dam construction that may increase vulnerability to climate change in many localities. Changing rainfall patterns that affect reservoir levels are likely to impact the availability of energy generation at the national level (DeLucena *et al*., 2009). Degradation of flora and fauna also result in additional greenhouse gas emissions (Fearnside, 1995).

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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. 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. However there is continuing debate in the region as to whether the grass strips prevent erosion, whether erosion is in fact the main problem, instead of soil fertility, and whether farmers still need slope stabilization (Forsyth and Walker, 2008).

Decision-making for large scale structural measures is often based on 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 potential for catastrophic disasters was increased and development intensified in armored areas only to be seriously devastated by events that exceed the engineering design level (Ericksen, 1986). While protection works often enable areas to be productively used and will continue to be needed for areas that are already densely settled, the so-called “levee effect”, often 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). Though building code regulations exist, non-adoption, especially in developing countries is problematic (Spence, 2004). Damages to the structure incur not only because of non-compliance with the codes, but also by a lack of inspections, the ownership status of the structure, and the political context and mechanisms of local governance (May and Burby, 1998).

5.2.2. Emergency Assistance and Disaster Relief

Humanitarian assistance is often required when other measures to reduce disasters have been unsuccessful. Such relief often helps to offset distress and suffering at the local level and to assist in recovery and rehabilitation. Sometimes external relief is unsuitable or inappropriate because the local people affected by disasters are not completely helpless or passive and are capable of helping themselves (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 the outer islands of small-island developing states, external assistance may be subject to considerable delay and self-help is an essential element of response, especially in the period before assistance arrives. 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. The disaster relief process has become highly sophisticated and much broader in scope over the past two decades involving both development and humanitarian organizations, with the increasing recognition that external relief providers make use of local knowledge in planning their relief efforts (Morgan, 1994).The relief itself 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 (Bynander *et al.*, 2005; Cahill, 2007).

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 Balcik, 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, although there have been improvements in recent years. 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 management (DRM) (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.

5.2.3. 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 (Lambin *et al.*, 2001). Local land use planning embedded in zoning, local comprehensive plans, and retreat and relocation policies is a popular approach to disaster risk management (Burby, 1998), 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 *et al.*, 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 temporary resettlement, land speculation, and creation of new vulnerabilities (Ingram *et al*., 2006; Jha *et al*., 2010). The government of Sri Lanka, for example, created buffer zones after the Indian Ocean tsunami of 2004, and relocated people to safer locations. However, distance from people's coastal livelihoods and social disruptions led to the revision of buffers and resettlement policies (Ingram *et al*., 2006). In the U.S., coastal retreat measures were difficult to implement as coastal property carries high value and wealthy property owners can exert political pressure to build along the coast (Ruppert, 2008). Shorefront property owners and realtors especially oppose setback regulations because they consider the regulation to deter growth (NOAA, 2007b).

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. Often systems of land tenure are very complex and flexible and contribute to vulnerability reduction as in the case of pastoralists in dryland environments where for example, sharing of land for grazing and of access to water are important drought responses (Anderson *et al*., 2010). There are also restrictions on land use planning in regards 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. As a result, most successful efforts to bring about reductions in exposure have been those that have been locally led and that build on successful local initiatives, and in many cases are informal measures rather than those imposed by governments at the local level (Satterthwaite *et al*., 2007).

Land acquisition is another means of 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 management (Godschalk *et al*., 2000) or climate change adaptation. 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), but this is rarely used in developing countries because of lack of resources and political will. Given the rapid population growth in coastal areas and in flood plains in many parts of the world, and 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, 2010b; Yohe *et al*., 1995). However, if sea level rise adversely affects local coastal areas some form of relocation may become necessary in all exposed jurisdictions.

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 *et al*., 2006). The 2004 Asian tsunami 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). Carbon sequestration is another benefit of ecosystem-based adaptation that includes sustainable watershed and community forest management (McCall, 2010).While the extent of their protective ecosystem functions is still debated (Gedan *et al*., 2011), the merits of the ecosystem services in general are proven, and development of quantified models of the services is well under way (Barbier *et al*., 2008; Nelson *et al*., 2009). These nonstructural measures are considered to be less intrusive and more sustainable, and when integrated with engineering responses provide mechanisms for adapting to disasters and climate extremes(Cheong, 2010a; Galloway, 2007; Opperman *et al*., 2009).

5.2.4. 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. Many localities produce food surpluses which enable them to manage during periods of seasonal or disaster initiated disruptions to their food supplies although such practices were more prevalent in pre-capitalist societies. In Pacific Island communities, for example, food crops such as taro and breadfruit were often stored for periods up to and exceeding a year by fermentation 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 many 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, migration, 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; Corbett, 1988; 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*. (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 storage (in advance) and 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. Clear rules outlining which consumers have priority in using water or electricity is important. It should be noted that using fossil fuels to generate electricity as an alternative to hydro production may be considered a maladaptive option if carbon capture and storage and other technologies to reduce emissions are not adopted.

Other elements that may be rationed as a result of natural hazards or disasters include prioritization of medical and health services where disasters may simultaneously cause large a spike in numbers requiring medical assistance and a reduction in medical facilities, equipment, pharmaceuticals and personnel. This may require classifying patients and giving precedence to those with the greatest need and the highest likelihood of a positive outcome. This approach seeks to achieve the best results for the largest number of people (Alexander, 2002; Iserson and Moskop, 2007).

5.2.5. Migration

Natural disasters are linked with population mobility in a number of ways (Hunter, 2005; Perch-Nielson *et al.*, 2008; Warner *et al.*, 2009). Evacuations 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).

Where climate change increases the marginality of livelihoods and settlements beyond a sustainable level, communities may be forced to migrate (McLeman and Smit, 2006). This may be caused by changing mean conditions through changes in extreme events or a combination of both. Extremes often serve as precipitating events (Hugo, 1996). Brown (2008b) 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 200 million 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 necessarily be a problem and indeed may be a positive adaptive response with people who remain at the place of origin benefitting from remittances (Barnett and Webber, 2009). Nomadic pastoralists migrate as part of their livelihoods but often respond to disruptive events by modifying their patterns of mobility (Anderson *et al.*, 2010).

Global estimations 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.* (2007) found that communities anticipating forced migration experienced stress. Hwang *et al.* (2010)(Hwang *et al.*, 2007) also found that forced migration directly led to increased levels of depression and the weakening of social safeguards in the relocation process.

One significant challenge for voluntary relocation particularly by property owners in countries without property insurance systems is that the investment connected to the affected property cannot be resold into the market. For some whose residential property loses value as a result of climate extremes and climate change, they may be unable to relocate and thus be forced to remain in place. Another 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). Community relocation schemes are those in which whole communities are relocated to a new non-exposed site. 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. 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).

5.2.6. Recovery and Reconstruction

Recovery and reconstruction include actions that seek to establish 'everyday life' of the locality affected by disaster (Hewitt, 1997). Often reconstruction enables communities and businesses 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) to achieve greater disaster resilience.

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). 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. Equally important, if indeed not more so, is the rehabilitation of livelihoods, and the addressing the problems of power inequities that often include land and resource grabbing by the economic and politically powerful after disaster in both developed and developing countries. Climate related disaster events, such as droughts do not always directly destroy the built environment infrastructure (like flooding or tropical cyclones) so the rehabilitation of livelihoods, in particular sustainable, livelihoods becomes 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*. (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).

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 local areas, to work with local residents and stakeholders 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), especially at the local scale.

5.3. Local 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. Proactive Behaviors and Actions

Capacity investments necessarily involve decisions based on prior disaster experiences and future disaster expectations, including those related to emergency response and disaster recovery. Researchers have identified some of the physical and social characteristics that allow for the prior adoption of effective partnerships and implementation practices during events (Birkland, 1997; Pulwarty and Melis, 2001). 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, increases in property value have driven attendant increases in economic losses (Changnon *et al.*, 2000; Pielke Jr. and Downton, 1999). Factors conditioning this outcome have been summed up by Burton *et al.* (Burton *et al.*, 2001) as “knowing better and losing even more”. In this context “knowing better” indicates the accumulation of readily available knowledge on drivers of impacts and effective risk management practices. 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.* (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.

5.3.1.1. Focusing Events for Local Action

Extreme events have been identified as offering “windows of opportunity” for including both disaster mitigation and long term risk management plans, such as for climate change adaptation, after particularly severe or visible events such as Hurricane Katrina or severe, sustained drought. In addition such a window can also create an opportunity for rebuilding or displacement programs that were decided upon a priori by the state or private sector. 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 (Anderson, 1994; Birkland, 1997; Kingdon, 1984), 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 impacts and changes that some focusing events engender can only be 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 with impacts ranging from health and economy to food security. The cumulative effects of such a disaster are clearly seen 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 recognition dealing with risk and insecurity is a central part of how poor people develop their livelihood strategies is giving rise to prioritizing disaster mitigation and preparedness as important components of many poverty alleviation agendas (Cuny, 1983; Olshansky and Kartez, 1998; 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 action is the application of spatial hazard information by planners. However, use of such information is likely only if the information is clearly mapped, comes from an authoritative and in many cases a local source, and provides specific guidelines for action and ease of implementation, and the locality is provided with evidence that the approaches have worked in other places (Olshansky and Kartez, 1998). 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 include land acquisition, density reduction, clustering of development, building codes for new construction, and mandatory retrofit of existing structures. The high cost land acquisition programs can make them unattractive to small communities (see 5.2.3). 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. However, 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.

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 (Berube and Katz, 2005; Bowden, 1981; Penning-Rowsell *et al.*, 2006; Pulwarty *et al.*, 2004). One important finding about locally-based 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) (see 5.2.1). 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 or increase risks in new locations through displacement (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.

5.3.1.2. Individual and Collective Behavior

At the household level and community level, individuals often engage in protective actions to minimize the impact of extreme events on themselves, their families, and their friends and neighbors. In some cases individuals ignore the warning messages and choose to stay in places of risk. 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, gender, 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 and Cutter, 1998; Dow and Cutter, 2000; Dow and Cutter, 2002; 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). Culture also plays an important role in evacuation decision making. For example, recent studies in Bangladesh have shown that there are high rates of non-evacuation despite improvements in warning systems and the construction of shelters. While there are a variety of reasons for this, gender issues (for example shelters were dominated by males, shelters didn't have separate spaces for males and females) have a major influence upon females not evacuating (Paul and Dutt, 2010a; Paul *et al*., 2010b).

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, gender (males will remain to protect and guard property, 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). Recent experience with hurricanes affecting Cuba suggests that such efforts are successful because there has been little loss of life.

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 (1976) in Southeast Asia, Watts (1983) in Western Africa and 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 5-4). For example, traditional political systems in the semiarid Limpopo Basin enabled chief's to reallocate surpluses during bad years but this practice has declined under contemporary systems where surpluses are sold (Dube and Sekhwela, 2008). In Northern Kenya social security networks existed among some groups of nomadic pastoralists that enabled food and livestock stock to be redistributed following drought events but these are also breaking down with the monetization of the local economy among other factors (Oba, 2001).

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Box 5-4. 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, a small island nation in the South West Pacific Ocean. 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 number of processes associated with colonialism (changes to the socio-political order), the introduction of the cash economy (the replacement of shell money) and conversion to Christianity (missionaries banned the suqe), 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). A variety of socio-political networks, that were used to offset disaster losses, existed throughout the Pacific region prior to colonization (Paulson, 1993; Paulson, 1993; Sahlins, 1962).

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Although the concept of moral economy is generally associated with pre-capitalist societies and those in transition to capitalism (in the past) significant features of moral economy, such as reciprocity, barter, crop sharing and other forms of cooperation among families and communities or community based management of agricultural lands, waters or woods are still part of the social reality of developing countries that cannot be considered anymore as pre-capitalist. Many studies show that moral economy based social relationships are still present such as traditional institutions regulating access, use and on-going redistribution of community owned land (Hughes, 2001; Rist *et al.*, 2003; Rist, 2000; Sundar and Jeffery, 1999; Trawick, 2001) The revitalization, enhancement and innovation of such moral economy based knowledge, technologies and forms of cooperation and interfamily organization represents an important and still existing source of fostering collective action that serves as an enabling condition for preventing and dealing with hazards related to natural resource management. While aspects of the traditional moral economy have declined in many societies, informal networks remain important in disaster risk reduction (see Section 5.3.5).

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). One means of mobilizing collective responses at the local level is through participatory approaches to disaster risk reduction such as Community Based Disaster Reduction (CBDR) or Community based Disaster Preparedness (CBDP) (see 5.3.2). Such approaches build on local needs and priorities, knowledge and social structures and are increasingly being used in relation to climate change adaptation (Reid *et al.*, 2009).

5.3.2. Anticipating Risk

In order to anticipate the risks and uncertainties associated with climate change there are a number of emerging approaches at the local level. One set of responses focuses on integrating information about changing climate risks into disaster planning and scenario assessments of the future. Another set of responses engages the effected community through community-based adaptation (CBA), where they help 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 (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 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 Red Cross and Red Crescent Societies, 2009). Whether or not such programs resulted in the delivery of relief faster is unknown.

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, including figures, tables and technical statements, into decisions on whether humanitarian organizations should act or not. 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 assessment of risk and identify responses than can enhance resilience by strengthening social-institutional measures including social relations (Allen, 2006; Patiño and Gauthier, 2009b). In assessing short and long term climate risks, the needs of vulnerable groups are often excluded (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; Patiño and Gauthier, 2009b), 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 (Burton *et al.*, 2007), the fact that it is resource-intensive (Van Aalst *et al.*, 2008) and recognizing that disempowerment occurs when local stories are distorted or not valued sufficiently (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). In the Philippines, the CBDP approach enabled a deeper understanding of local-specific vulnerability than previous disaster management contexts, which 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 recognizes the drivers at multiple scales, including the municipalities and national levels.

CBA responses provide increased participation and recognition of the local context, which is important when adapting to climate change (see Box 5-5). 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 (Douglas *et al.*, 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 marginalized 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 organization 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. Following a severe drought (2003-2005) and a perceived increase in weather variability, the Heiveld farmers decided to monitor the local climate and to discuss seasonal forecasts and possible strategies in quarterly climate change preparedness workshops. These workshops are facilitated in collaboration with two local NGOs (Indigo and EMG). They are also supported by scientists to address farmers' questions in a participatory action research approach – to ensure that local knowledge and scientific input can be combined to increase the resilience of local livelihoods.

The Heiveld Co-operative has been an important organizational vehicle for this learning process, strongly supported by their long term partners, with the focus on supporting the development of possible adaptation strategies through a joint learning approach to respond to and prepare for climate variability and change. Adaptive capacity has been built by recognizing local conditions, integrating local knowledge with scientific climate information and driven by a positive vision of affected communities and how they can build sustained resilience in the face of environmental, economic and social change.

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5.3.3. Communicating Risk

Both anticipating and responding to risk entails communications among and between localities, public officials, and experts. However, communicating the likelihood of extreme impacts of climate change presents an important and difficult challenge (Moser and Dilling, 2007). Effective communication is necessary across the full cycle of disaster management: reduction, preparedness, response, recovery. 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 can be 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).

5.3.3.1. Risk Information and Messaging

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 include: 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, 2006) (see Box 5-6 for additional sources of risk information).

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Box 5-6. 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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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 a variety of information source vehicles including 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 information 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. In addition within community discussion on risks to livelihoods, such as during droughts, act as mechanisms for risk communication and response actions (Dekens, 2007).

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 local 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, 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. Little research attention has been devoted to how information can be distributed within a family, although the existing research does show there are emotional, social, and structural barriers to such distribution (Norgaard, 2009). 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. Such gaps are evident in developed as well as lesser developed regions.

5.3.3.2. Local Communication Channels

The degree of acceptability of information and trust in the providers, dictate the context of communicating disaster and climate information (see Box 5-7). Lindell and Perry (2004) 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; Fischhoff, 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 carried out as joint problem definition and fact-finding strategies 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 including revisiting potential usefulness for past events experienced; 4) interacting with actual and potential users to better understand informational needs, desired formats of information, and timeliness of delivery; 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 5-7. 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; Fischhoff, 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?

_____ END BOX 5-7 HERE _____

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 multiple pathways of communication that engenders credibility, trust and cooperation (Frumkin and McMichael, 2008; NRC, 1989), which are especially important in high-stress situations such as extreme impacts of climate change. For example, participatory video production is effective in communicating the extreme impacts of climate change (Baumhardt *et al*., 2009; Suarez *et al*., 2008). Participatory video involves a community or group in creating their own videos through story-boarding and production (Lunch and Lunch, 2006). Such projects are traditionally used in contexts, such as poor communities, where there are constraints to accurate climate information (Patt and Gwata, 2002; Patt and Schröter, 2008). 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 (McCall, 2008; Shaw *et al*., 2009a). 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.

5.3.3.3. Warnings and Warning Systems

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). 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 at the local scale 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 Gwata, 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).

Significant advancements in warning systems in terms of improved monitoring, instrumentation, and data collection have occurred (see Box 5-8), 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 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 (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.

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 and trusted communication processes are necessary to generate local confidence and preparedness for climate change (Fischhoff, 2007). The very discussion of climate forecasts and projections within potentially impacted communities has served as a vehicle for democratizing the drought discourse in Ceará in Northeast Brazil (Finan and Nelson, 2001). 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 local area and the need to perform basic emergency functions—pre-event assessments, proactive hazards mitigation, incident management (Lindell and Perry, 1996). As noted in previous IPCC Reports (IPCC, 2007a), preparing for short-term disasters enhances the capacity to adapt to longer term climate change.

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Box 5-8. The Famine Early Warning Systems Network (FEWS NET)

The Famine Early Warning Systems Network (FEWS NET) is a USAID-funded activity that collaborates with international, regional and national partners to provide timely and rigorous early warning and vulnerability information on emerging and evolving food security issues(Brown, 2008a). FEWS NET professionals in the Africa, Central America, Haiti, Afghanistan and the United States monitor and analyze relevant data and information in terms of its impacts on livelihoods and markets to identify potential threats to food security. Once these issues are identified, FEWS NET uses a suite of communications and decision support products to help decision-makers act to mitigate food insecurity. These products include monthly food security updates for 25 countries, regular food security outlooks, and alerts, as well as briefings and support to contingency and response planning efforts. More in-depth studies in areas such as livelihoods and markets provide additional information to support analysis as well as program and policy development.

FEWS NET focuses its efforts on strengthening early warning and food security networks through a suite of communications and decision support products (see www.fews.net/ml/en/products). Climate monitoring and forecasting are especially important given the large number of rural people dependent on subsistence agriculture and pastoralism. Because conventional climate station networks are sparse, remote sensing and modeling methods have been developed to supplement conventional climate analysis. FEWS NET employs a livelihoods framework to geographically characterize vulnerability and interpret hazards. By assembling information on how households access food and income, routine monitoring of rainfall, vegetation, crops, and market prices is made more meaningful. Key food security questions are more readily answered, such as: Which population groups are facing food insecurity, and for how long? What are the best ways to mitigate adverse trends or shocks to their livelihood systems?

Early warning triggers the contingency planning process. FEWS Early Warning and Response engages in a series of steps depending on the phase of intervention (before during, after etc.):
1. *Pre-season Vulnerability Assessment and Profiles of At-Risk Groups*. FEWS analysis conducted prior to the growing season to identify populations likely to be hit hard in the case of a drought or other shock.
2. *Seasonal Monitoring*. Reading and reporting of satellite imagery on rainfall and crop growth and cereal price data produced by a number of different groups and collated by FEWS.
3. *Special Alerts and Warning*. Briefings, cables, and emails to USAID by FEWS to inform of potential food emergencies.
4. *Contingency Planning including scenario development*. Intra-USAID mission efforts undertaken during poor production years monitor food security situation and determine appropriate responses. The contingency planning

group, which includes the FEWS Report, uses a number of monitoring instruments.
5. *Response plan development and implementation*. Based on a needs assessment, response objectives and programs to meet those objectives need to be defined. Arrangements and procedures to implement these programs also need to be defined, as do the material, human resources and financial resources required. If a good contingency plan has been developed, this can be adapted, based on assessment results, and become a response plan.
6. *Aid Intervention Evaluation*. Selective assessments are conducted with FEWS involvement, to (i) understand targeting methods used by NGOs; (ii) gain insight into nature of vulnerability; and (iii) observe community status after intervention.

Monitoring and evaluation of response, impact and changes in needs is an ongoing process, before, during, and after. While regular monitoring of progress should identify problems and ways to improve interventions during the response, afterward a more detailed evaluation needs to be undertaken. The lessons learned should be identified and incorporated into future contingency plans and response mechanisms, thus providing the necessary feed-back loop for disaster risk communication.

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5.3.4. Empowerment for Local Decision Making

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; Mustafa, 1998; Polack, 2008) and disempowerment (Hewitt, 1997) 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). In the Philippines, for example, Allen (2006) found that many aspects of community disaster preparedness such as building on local institutions and structures, building local capacity to act independently, and building confidence through achieving project outcomes were already present. She also found that where agencies focused on the physical hazard as the cause of disasters and neglected the underlying causes of the social vulnerability within these small specific projects, disempowerment may result. 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 or responsibility for 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. Empowerment and ownership of the disaster impacts may be particularly important in achieving useful (for the locality) post-disaster assessments (Pelling, 2007). It is important for external actors to identify those voices who speak for the local constituencies.

5.3.5. Social Drivers

Similar to empowerment is the role of localized social norms, social capital, and social networks as these also 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 (see Chapter 2), 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 and Kelly, 1999). Norms regarding gender also play a role in determining outcomes. For example, women were more likely to drown than men during the Asian tsunami because they were less able to swim (Rofi *et al.*, 2006).

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 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, 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). While often positive, social capital can have some negative outcomes. Internal social networks are oftentimes self-referential and insular (Dale and Newman, 2010; Portes and Landolt, 1996). This results in a closed society that lacks 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 facilitating 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). 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). Such opinion leaders may span a range of types, from formally-elected officials, celebrities and well-known leaders, to local community members who are well-embedded in local social networks. 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 impacts of climate change itself may also change the structure and utility of social networks. As people migrate away from climate risks, those left behind can experience fragmented or weakened social networks. 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).

5.3.6. 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*., 2009a). 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, community participation in disaster management is essential to tap this information as it can offer alternative perspectives and approaches to problem-solving (Battista and Baas, 2004; Turner and Clifton, 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 as well as actively adapting to the changes (Macchi *et al*., 2008; Salick and Byg, 2007; Salick and Ross, 2009; Turner and Clifton, 2009). Research is emerging in helping to document changes that indigenous people (people living with local and traditional cultures) are experiencing (Ensor and Berger, 2009; Salick and Ross, 2009). Although this evidence might be similar to scientific observations from external researchers, the fact that local communities are observing it is initiating discussions about 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).

Local knowledge is also an important anchor for communities in the integration of local knowledge with external scientific, global, and technical knowledge. Further, experiences in environmental management and integrated assessment suggest mechanisms for such knowledge transfers from the bottom up and from the top down (Burton *et al*., 2007; Prabhakar, S. V. R. K. *et al*., 2009). For example, communities set up trusted intermediaries to transfer and communicate external knowledge such as technology –based early warning systems that incorporate the local knowledge system (Bamdad, 2005; Kristjanson *et al*., 2009). Another example is the re-engineering of local practices to adapt to climate change as shown in the conversion of traditional dry-climate adobe construction to more stabilized earth construction built to withstand regular rainfall. The utilization of participatory methods to draw in the perspectives of local stakeholders for subsequent input into hazards vulnerability assessments or climate change modeling or scenario development is well documented (see Section 5.3.3).

Obstacles to utilizing local knowledge exist. Climate-induced biodiversity change threatens historical coping strategies of indigenous people as they depend on the variety of wild plants, crops and their environments particularly in times of disaster (Turner and Clifton, 2009). 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).

5.3.7. Local Government and Non-Government Initiatives and Practices

Governance structures are pivotal to addressing disaster risk and informing responses as they help shape efficiency, effectiveness, equity, and legitimacy (Adger *et al*., 2003), resulting in poorer countries with weaker governance experiencing concentrated global disaster risk (UNISDR, 2009). In some places, climate change management practices have been 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) but could also be based on old practices of operations. In many places, actions emerging at the local level are context-specific and tailored to local contexts (Bizikova *et al*., 2008) . 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).

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 (Birkmann *et al*., 2010; Heinrichs *et al*., 2009). 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. ICLEI, a non-profit network of more than 1200 local government members across the globe provides web-based information (www.iclei.org) in support of local sustainability efforts using customized tools and case studies on assessing climate resilience and climate change adaptation.

An assessment of the current state of progress on adaptation in eight cities (Bogotá, Cape Town, Delhi, Pearl River Delta, Pune, Santiago, Sao Paulo and Singapore) suggests that adaptation tend to support existing disaster management strategies (Heinrichs *et al*., 2009). Another study comparing both formal adaptation plans and less formal adaptation studies in nine cities including Boston, Cape Town, Halifax, Ho Chi Minh City, London, New York, Rotterdam, Singapore, and Toronto suggests that the focus is mostly on risk reduction and the protection of citizens and infrastructure, with Rotterdam seeing adaptation as opportunity for transformation (Birkmann *et al*., 2010). 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. Despite the intention that city adaptation responses aim at an integrated approach, they tend to have sectoral responses, with limited integration of local voices. Unfortunately with many of these cases, there is a good understanding of the impacts, 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 *et al*., 2007) and can be applicable to adaptation policies. Lack of resources and capabilities has lead to outsourcing of local adaptation plans, and can generate insensitive and unrefined local solutions and technological fixes (Crabbé, 2006).

The history and process of decentralization are 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 (Roberts, 2008; Van Aalst *et al*., 2008). The case of decentralization in climate change adaptation is relatively new, and we can draw some lessons from decentralized natural resource management and crisis management. One of the problems of decentralization has been the complexity and uniqueness of each locality that policy planners often failed to take into account because of the lack of understanding and consultation with the local community, and this could result in recentralizing the entire process in some instances (Geiser and Rist, 2009; Ribot *et al*., 2006). Some remedies include working with local institutions, ensuring appropriate transfer of various rights and access, and providing sufficient time for the process (Ribot, 2003). The crisis management literature also points out that there has been a lack of coordination and integration between central and local governments (Schneider, 2008; Waugh and Streib, 2006). Moynihan (2009) suggests a networked collaboration as a solution and posits that even a hierarchical disaster management structure such as the incident command system in the U.S. operates on the network principles of negotiation, trust, and reciprocity.

Although government actors play a key role, it is evident that partnerships between public, civic, and private actors are crucial in addressing climate hazards-related adaptation (Agrawal, 2009). While international agencies, the private sector, 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)) This can be seen in the case of New York City Panel on Climate Change that acted as a scientific advisory group to both the Mayor Bloomberg's Office of Long-term Planning and Sustainability and the New York City Climate Change Adaptation Task Force, a stakeholder group of approximately 40 public agencies and private-sector organizations that manage the critical infrastructure of the region (Rosenzweig *et al*., 2011). The Panel and stakeholders separated functions between scientists (knowledge provision) and stakeholders (planning and action), communicated climate change uncertainties, with the coordination by the Mayor's office (Rosenzweig *et al*., 2011).

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 district 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 risk management into normal policies addressing social welfare, quality of life, infrastructure, and livelihoods; and 2) incorporating a multi-hazards approach into planning and action. Differences in coping and adaptation along with the costs of managing disaster risk at the local level present challenges and opportunities for adaptation to climate extremes.

5.4.1. Differences in Coping and Risk Management

There are significant differences among localities and population groups in the ability to prepare for, respond to, recover from and adapt to disasters and climate extremes. During the last century, social science researchers have examined those factors that influence coping responses by households and local entities through post-disaster field investigations as well as pre-disaster assessments (Mileti, 1999; NRC, 2006). Among the most significant individual characteristics are gender, age, wealth, ethnicity, livelihoods, entitlements, health, and settlements. 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), and also in the differential mortality from disasters (Neumayer and Plümper, 2007). In disasters, women tend to have different coping strategies and constraints on actions than men (Fothergill, 1996; Morrow and Enarson, 1996; Peacock *et al*., 1997). These are due to the socialized gender factors such as social position (class), marital status, education, wealth, and caregiver roles, as well as physical differences in stature and endurance. At the local level for example, women's lack of mobility and social isolation found in many places across the globe tend to augment disaster risk, and vulnerability(Clot and Carter, 2009; League of Red Cross and Red Crescent Societies, 1991; Mutton and Haque, 2004; Schroeder, 1987). Relief and recovery operations are often insensitive to gender issues (Hamilton and Halvorson, 2007), and so the provision of such supplies and services also influences the differential capacities to cope (Ariyabandu, 2006; Enarson, 2000; Fulu, 2007; Wachtendorf *et al.*, 2006), especially at the local level. However, the active participation of women has been shown to increase the effectiveness of prevention, disaster relief, recovery and reconstruction (Enarson and Morrow, 1997). Based on the literature, opportunities arise in disaster risk management for the incorporation of gender-sensitive needs into disaster planning and response through the inclusion of women's indigenous knowledge as well as the promotion of literacy, provision of avenues for women's active engagement in the recovery process, and the assurance of access to physical and psychological resources, and legal protections (Hamilton and Halvorson, 2007)(see Box 5-9).

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Box 5-9. 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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5.4.1.2. 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 hearing loss, 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). Children have their own knowledge of hazards, hazardous places, and vulnerability that is often different than adults (Gaillard and Pangilinan, M. L. C. J. D., 2010; Plush, 2009). 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 (Barrett *et al.*, 2008; Weems and Overstreet, 2008). In addition to physical impacts and safety (Lauten and Lietz, 2008; Weissbecker *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 (Bartlett, 2008; Manyena *et al.*, 2008; Mitchell *et al.*, 2008; Pfefferbaum *et al.*, 2008; Ronan *et al.*, 2008; Williams *et al.*, 2008).

5.4.1.3. Wealth

The level of wealth at the local level affects the ability of a households or localities to prepare for, respond to, and rebound from disaster events (Cutter *et al.*, 2003; Masozera *et al.*, 2007). Wealthier places 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 localities 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 localities 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.

In some localities, it is not just wealth or poverty that influence coping strategies and disaster risk management, but rather the interaction between wealth, power, and status, that through time and across space has led to a complicated system of social stratification (Heinz Center, 2002). One of the best examples of this is the human experience with Hurricane Katrina (see Box 5-10).

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Box 5-10. Case Study – Hurricane Katrina Recovery and Reconstruction

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).

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). 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). In terms of longer term recovery, New Orleans is progressing with estimates suggesting a time frame that is likely to take 8-11 years (Kates et al. 2006). However, large losses in population, housing, and employment suggest a pattern of only partial recovery for the city with significant differences in the location and the timing at the neighbourhood or community level (Finch *et al.*, 2010).

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5.4.1.4. 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). Another definition of livelihoods gives more emphasis to access to assets and activities that is influenced by social relations (gender, class, kin, and belief systems) and institutions (Ellis, 2000). Understanding how natural resource-dependent people cope with climate change in the context of wider livelihood influences is critical to formulating valid adaptation frameworks.

Local people's livelihoods and their access and control of resources can be affected by events largely beyond their control such as climatic extremes (floods, droughts) conflict, or agricultural problems such as pests and disease and economic shocks that can largely impact their livelihoods (Chambers and Conway, 1992; Jones *et al*., 2010). For poor communities living on fragile and degraded lands such as steep hillsides, dry lands and floodplains, climate extremes present additional threats to their livelihoods that could be lost completely if exposed to repeated disastrous events with short intervals not sufficient for recovery. Actions aiming at improving their adaptive capacity focus more on addressing the deteriorating environmental conditions that undermine livelihoods and capacity to cope. A central element in their adaptation strategies involve ecosystem management and restoration activities such as watershed rehabilitation, agroecology and forest landscape restoration, (Ellis, 2000; Ellis and Allison, 2004; Osman-Elasha, 2006b)**.** These types of interventions protect and enhance natural resources at the local scale and address immediate development priorities, but also improve local capacities to adapt to future climate change (Spanger-Siegfried *et al*., 2005).

A number of studies indicated that 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 5.2.2). 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). Diversification within and beyond agriculture which contributes to spreading risk is a widely recognized strategy for reducing risk and increasing well-being in many developing countries (Ellis, 2000; Ellis and Allison, 2004).

5.4.1.5. Entitlements

Entitlements are based on the assets of the individuals and household. Assets are broadly defined and include not only physical assets such as land, but also human capital such as education and training. At the local scale assets include institutional assets such as technical assistance or credit; social capital such as mutual assistance networks; and public assets such as basic infrastructure like water and sanitation. The link between disaster risk, access to resources, and adaptation has been widely documented in the literature (Adger, 2000; Brooks, 2003). 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.

Declining access to resources and ownership 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 *et al*., 2009).

Assessment of livelihoods provides the explanation as to the differences in responses based on the understanding of endowments, entitlements and capabilities, within the organizational structure and power relations of individuals, households, communities, and other local entities (Scoones, 1998). Access to assets and entitlements is key to improving the ability of localities to lessen their vulnerability and to cope with and respond to disasters and environmental change. However, in some cases this may not be true, for example, if a disaster affects a household asset, but they household is still paying off its debt regarding the initial cost of the asset and assuming that the asset is not protected or insured against hazards, the asset loss coupled with the need to pay off the loan renders the household more vulnerable (Twigg, 2001). Entitlement protection thus requires adaptive types of institutions and patterns of behaviour (Bohle *et al*., 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.

Adaptive capacity is also influenced to a large extent by the institutional rules and behavioural norms that govern individual responses to hazards (Dulal *et al*., 2010). It is also socially differentiated along the lines of age, ethnicity, class, religion, and gender (Adger *et al*., 2007). Local institutions regulate the access to adaptation resources, and it has been suggested that institutions which ensure equitable opportunities for access to resources are likely to promote adaptive capacity within communities and other local entities (Jones *et al*., 2010) . 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 *et al*., 2009). Better management of disaster risk also maximizes use of available resources for adapting to climate change (Kryspin-Watson *et al*., 2006).

5.4.1.6. Health and Disability

Initial estimates of the global impacts of climate change suggest nearly 160,000 annual human deaths are caused by vector borne diseases, food insecurity, heat waves, and other problems (Campbell-Lendrum *et al*., 2003). However, this is likely an underestimate since it based on modeling and not actual observations. The extreme impacts of climate change (Chapters 3 and 4) are likely to directly or indirectly affect the health of many populations. Heat waves lead to heatstroke, while cardiopulmonary problems and respiratory illness are linked to shifts in air pollution concentrations such as ozone that often increase with higher temperatures (Bernard *et al*., 2001). Heat waves differentially affect populations based on their race, gender, age (Díaz *et al*., 2002), and medical and socioeconomic status (O'Neill and Ebi, 2009), consequently raising concerns about health inequalities (see Chapter 9). Health inequalities are of concern in extreme impacts of climate change more generally, as those with the least resources have the least ability to adapt making the poor and disenfranchised most vulnerable to climate-related illnesses (McMichael *et al*., 2008). For extreme events, pre-existing health conditions that characterize vulnerable populations 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 (Bourque *et al*., 2006; Few and Matthies, 2006; Shoaf and Rottmann, 2000).

Other illnesses linked to climate change affect localities and are best managed at that scale. A range of vector-borne illnesses has been linked to climate, including malaria, dengue, Hantavirus, Bluetongue, Ross River Virus, and cholera (Patz *et al*., 2005). Vector-borne illnesses have been 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. Pools of standing water which are breeding grounds for mosquitoes promise to expand, therefore increasing illness exposure (Depradine and Lovell, 2004). At the same time, some literature shows that climate change will dry mosquito habitat, therefore reducing illness rates (Mouchet *et al*.). Much of the nuance of this literature is due to the location-specific nature of these outcomes. Therefore, vector-control programs will be best suited to the local characteristics of changing risks. In addition, there are a variety of social factors that have the potential to influence disease rates that are most suitably managed at the sub-national level or urban scale. For instance, certain types of population growth or change may increase risk and affect disease rates (Patz *et al*., 2005). Vector control programs generally implemented at the local level also have the potential to influence outcomes (Tanser *et al*., 2003). Infectious disease patterns also have the potential to change dramatically, necessitating improved prevention on the part of local providers that have specific knowledge of localized environmental change (Parkinson and Butler, 2005). Cholera, for example, has seasonal variation that may be directly affected by climate change (Koelle *et al*., 2004).

There is concern regarding the mental health impacts of acute climate events, such as storms and floods that lead to destruction of livelihoods and displacement, especially for vulnerable populations (Balaban, 2006). In some hurricanes, the mental health of residents in affected communities is extremely negatively impacted over an extended period of time (Weisler *et al*., 2006). Policy responses to the event were insufficient to manage these impacts, and provide a lesson for future events where greater mental health services may be necessary (Lambrew and Shalala, 2006). Managing public health and disability is important in the response to disasters (Shoaf and Rottmann, 2000).

5.4.1.7. Human Settlements

Settlement patterns are another factor that influences disaster risk management and coping with extremes. Human settlements differ in their physical and governance structures, population growth patterns, as well as in the types, drivers, impacts, and responses to disasters. As noted earlier (see section 5.4.1.4) rural livelihoods and poverty are the drivers of disaster risk, Poverty, resource scarcity, access to resources, as well as inaccessibility 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 towns and 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).

One important locality receiving considerable research and policy attention are megacities due to the density of infrastructure, the population at risk, the growing number and location of informal settlements, and the complexity of governance and disaster risk management. Given the rapid rate of growth in the largest of these world's cities and the increasing urbanization, 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 (Kraas *et al*., 2005; Munich Re Group, 2004; Wenzel *et al*., 2007). 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 disaster risk 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, informal settlements)(Wisner and Uitto, 2009). Many megacities are seriously compromised in their ability to prepare for and respond to present disasters, let alone adapt to future ones influenced by climate change (Fuchs, 2009; Heinrichs *et al*., 2009; Prasad *et al*., 2009).

However, it is not only the megacities that pose challenges, but the overall growth in urban populations. Currently more than half of the global population 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 (UNISDR, 2009). 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. It is likely that increased urbanization could limit not only the adaptive capacity of urban areas, but rural areas as well.

5.4.2. Costs of Managing Disaster Risk and Risk from Climate Extremes

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. Total losses can be separated into direct and indirect losses (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 as important as it evaluates the overall economic impact of the disaster on society. At the local scale, the assessment of indirect losses is difficult because of the limited availability of economic data at this level. Most economic data (e.g., input-output table, income data) are available at the national scale, and direct loss estimates are generally aggregated at the national scale. In addition, the intricate linkages of the affected area and the world can complicate the assessment as well as the difficulty of establishing the boundary of local analyses. 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, thus, need to be considered in accounting for indirect losses at the local level. Disaster loss estimates are, therefore, highly dependent on the scale of the analysis, and results can be very different between community-scale and subregional-scale analyses.

Despite the difficulties noted above, many local studies exist. For example, 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 impact 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 (2010) 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. Rodriguez-Oreggia *et al.* (2009) focused on poverty and the World Bank's Human Development Index at the municipality level in Mexico, and demonstrated that municipalities affected by disasters saw an increase in poverty by 1.5% to 3.6%. 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.

Using firm-level surveys at the local scale, Kroll *et al.* (1991), Tierney (1997), and Boarnet (1998) investigate the consequences of lifeline and transportation interruption of firm activity and survival for the Loma Prieta earthquake in 1989 and the Northridge earthquake in 1994. They found that the local consequences of infrastructure-related indirect impacts are often larger than the direct impact on firms, and this result is likely to be valid for large-scale climate-related disasters. West and Lenze (1994) summarize the impact of Hurricane Andrew on Florida, including local job market consequences. The U.S. Bureau of Labor Statistics (2006) also provides a detailed analysis of the large labor market consequences of Hurricane Katrina within Louisiana. Using household survey in three counties and 16 cities after the 2004 hurricane landfalls in Florida, Smith and McCarty (2006) show that households are more often forced to move outside the affected area by infrastructure problems than by structural damages to their home. Modelling approaches are also used to assess disaster indirect losses at sub-national levels. These approaches include input-output (IO) models (Haimes *et al.*, 2005; Hallegatte, 2008; Okuyama, 2004) and Computable General Equilibrium (CGE) models (Rose *et al.*, 1997; Rose and Liao, 2005; Tsuchiya *et al.*, 2007). Most of the published analyses are carried out in developed countries. There is a clear lack of research on disaster estimates in developing countries, and it is a big gap in need of further research.

5.4.2.2. Adaptation and Risk Management – Present and Future

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 and 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 *et al.*, 2008). In developed countries, there are cost differences in adaptation strategies between urban and rural areas. For example, in Japan disaster damage is several hundred times more costly in urban than in rural areas, often necessitating different disaster risk management strategies depending on cost-benefit analysis (Kazama *et al.*, 2009).

Though disaster risk management and adaptation policies are closely linked, few integrated cost analyses of risk management and adaptation are available at the local level. One example draws from recent studies of the cost of city-scale adaptation. Rosenzweig and colleagues (Rosenzweig *et al.*, 2011; Rosenzweig *et al.*, 2007) developed a sophisticated analytical response to a projected fall in water availability in New York. This frames adaptation assessment within a step-wise decision analysis by identifying and quantifying impact risks before identifying adaptation options that are then screened, evaluated and finally implemented. Hallegatte *et al.* (2008a), Hallegatte *et al.* (2008b), and Ranger *et al.* (2010) use a simplified catastrophe risk assessment to calculate the direct costs of storm surges under scenarios of sea level rise coupled with an economic input-output (IO) model for Copenhagen and Mumbai. 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. Results show that the consideration of adaptation is an important element in the economic assessment of extreme disaster risks related to climate change (Hallegatte *et al.*, 2010).

Ranger et al. (2010) evaluated the risk of heavy rainfall in Mumbai, and concluded that total direct and indirect losses associated with a 1-in-100 year event could rise by 200% (i.e. triple) in the 2070's compared with current estimate of $690 to $1890 million that includes indirect losses of $100 to $400 million. They also note that a combined adaptation and risk management approach could significantly reduce future losses. Estimates suggest, for instance, that by improving the drainage system in Mumbai, losses associated with a 1-in-100 year flood event could be reduced by as much as 70%. This means that the annual losses could be reduced in absolute terms compared with the current level, even with climate change. Full insurance coverage of flooding could also cut the indirect cost by half. These analyses highlight the fact adaptation to extreme events and climate change can focus on reducing the direct losses (e.g., through the upgrade of coastal defences) or indirect losses by making the economy more robust, utilizing insurance schemes, or public policies to support small businesses after the disaster.

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). Moreover, disaster loss estimates are carried out for various purposes (e.g., assessment of foreign aid needs; cost-benefit analysis of protection investments) (IBRD and WB, 2010). Depending on the purpose, the spatial boundaries of the analysis are different (investigating losses only, or taking into account gains) and the conceptual boundaries are different (including or not non-market losses). Comparing disaster loss data requires taking into account of these differences in boundaries and purposes.

Similarly, there is some ambiguity on impact and adaptation costs that affect local-level economic analyses. The lack of consensus on physical impacts of climate change and adaptive capacity (see Chapter 4); on the discount rate (Heal, 1997; Nordhaus, 2007; Stern, 2007; Tol, 2003; Weitzman, 2007); and on the evaluation of non-market costs, especially the value of biodiversity or cultural heritage (Pearce, 1994) create some uncertainty on local impact and adaptation costs. 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, 2007).

5.4.3. Limits to Adaptation

Limits and barriers to local adaptation are generally grouped into three interconnected categories: ecological and physical; human informational limitations related to knowledge, technology, economics, and finances; and psychological, behavioral, and socio-cultural barriers (Adger *et al*., 2010; ICIMOD, 2009). The social and cultural limits to adaptation are not well researched, with little attention within the climate change literature devoted to this thus far.

The lack of access to information by local people has restricted improvements in knowledge, understanding, and skills—needed elements in helping localities undertake improved measures to protect themselves against disasters and climate change impacts (Agrawal *et al*., 2008). The information gap is particularly evident in many developing countries with limited capacity to collect, analyze and use scientific data on mortality and demographic trends, as well as evolving environmental conditions (Carraro *et al*., 2003; IDRC, 2002; National Research Council, 2007). Based on Fischer *et al*. (2001) closing the information gap is critical to reducing climate change related threats to rural livelihoods and food security in Africa.

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). For example, localities in areas prone to climate extremes such as frequent drought have developed certain coping responses that assist them in surviving harsh conditions. Over time, such coping responses proved inadequate due to the magnitude of the problem (Ziervogel *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 (United Nations, 2008). Another example is teaching women to swim, especially in tsunami-prone coastal areas.

In terms of financial limitations and despite the potential contribution of microfinance to vulnerability reduction among the world's poor, certain risks have been identified that should be considered from the perspective of adaptation to climate change. For example microfinance services typically do not reach the poorest and most vulnerable groups at local levels who have urgent and immediate needs to be addressed (Helms, 2006). The ability of a community to ensure equitable access and entitlement to key resources and assets should be seen as key to building local adaptive capacity.

In developed countries, household decisions regarding disaster risk reduction, and 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 meter for homes built from 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.

Local-level adaptation actions, in many cases are portrayed as reactive and short term, unlike the higher-level national or regional plans which are considered anticipatory and involve formulation of policies and programs

(Bohle, 2001; Burton *et al*., 2003). Poverty, increased urbanization, and climatic shocks limit the capacity to initiate planned livelihoods adaptations at the local scale. 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 places 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, 2008b).

As the above paragraphs show, the main challenge for local adaptation to climate extremes is to find a good balance of measures that simultaneously address fundamental issues related to the local enhancement of local collective actions, and the creation of subsidiary structures at national and international scales that complement such local actions. This means that the localized expression of the type, frequency, and extremeness of climate-sensitive hazards will be set within these national and international contexts.

5.4.4. Advancing Social and Environmental Justice

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). There is less research on the mechanisms or practical actions needed for advancing social and environmental justice at the local scale. This is an important gap in the literature.

5.5. Management Strategies

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 hazard 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 modeling of 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) (see Chapter 2). Of particular note are those studies focused on assessing the sub-national exposure to coastal hazards (Gornitz *et al*., 1994; Hammar-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 (Bankoff *et al*., 2004; Birkmann, 2006), 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; 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™) (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; Brenkert and Malone, 2005; O'Brien *et al*., 2004). 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 U.S. (Oxfam, 2009).

However, the full integration of hazard 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). It is also related to the difficulties of working across disciplinary or knowledge boundaries.

The development of methodologies and metrics for climate adaptation assessments are emerging and mostly derivative of the methodologies employed in vulnerability assessments noted above. For example, some are extensions or modifications of community vulnerability assessment (CRA) methodologies and employ community participatory approaches such as those used by World Vision (Greene, n.d.). Still others begin with livelihood or risk assessment frameworks and use a wide range of techniques including multi-criteria decision analyses (Eakin and Bojorquez-Tapia, 2008); index construction (Vescovi *et al*., 2009); segmentation and regional to global comparisons (Torresan *et al*., 2008), and scenarios (Wilby *et al*., 2009).

5.5.2. Risk Sharing and Transfer at the Local Level

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 that “share” risk (e.g. remittances) and formal market instruments that “transfer” risks for a price (e.g., insurance), can be an essential part of an overall adaptation strategy. They do not explicitly reduce overall risk or direct losses, and in the case of insurance clients can expect to pay more than their expected 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 (Linnerooth-Bayer *et al*., 2005).

Informal risk sharing practices are common and important for post-disaster relief and reconstruction. In the absence of more formal mechanisms like insurance, those incurring losses may employ diverse non-insurance financial coping strategies, such as relying on the solidarity of international aid, remittances, selling and pawning fungible assets and borrowing from money lenders. At-risk individuals in low-income countries rely extensively on reciprocal exchange, kinship ties and community self help. For example, often women in high risk areas engage in innovative ways to access post-disaster capital by joining informal risk-hedging schemes, becoming clients of multiple micro-finance institutions, or maintaining reciprocal social relationships. Combined analysis of multiple surveys indicates that about 40% of households in low- and lower-middle income countries are involved in private transfers in a given year as recipients or donors (Davies and Leavy, 2007).

Households in disaster-prone slum areas in El Salvador spend an average of 9.2 percent of their yearly income on risk management, including financing emergency relief and recovery (Wamsler, 2007). A particularly important informal risk sharing mechanism is remittances, or transfers of money from foreign workers to their home countries (discussed further in section 7.4.5.2). Household saving can be accesses from a bank, but they can also be in the form of stockpiles of food, grains, seeds and fungible assets. Small savings institutions, however, can be directly impacted by catastrophes, which can result in insufficient liquidity to handle a run on their accounts, as occurred during the 1998 floods in Bangladesh (Kull, 2006). Lacking sufficient savings, many disaster victims take out loans to cover their post-disaster expenses. The 18-60% interest rate charged on formal micro-credit, although relatively high, is generally far below the 120-300% often charged by local moneylenders (Linnerooth-Bayer and Mechler, 2009). Such "loan sharking" is most common after disasters when demand is high.

Insurance, including microinsurance, is the most common formal risk transfer mechanism at the local level. An insurance contract spreads stochastic losses geographically and temporally, and can assure timely liquidity for the recovery and reconstruction process. As such, it 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, disaster preparation and disaster mitigation. Where insurance is applied without adequate risk reduction, it can be a disincentive for adaptation, as individuals may rely on insurance to manage their risks and are left overly 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. However, coverage is heterogeneous across countries and lines of business (Vellinga *et al.*, 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 *et al.*, 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 (+15% per year between 1998 and 2008) outstripping that in the developed world (Swiss Re, 2009). In 2008, total premiums from emerging economies stood at just over $0.5 trillion USD. Insurance has a much lower penetration in developing countries; here it covers only around 3 percent of disaster losses (Höppe and Gurenko, 2006) and mainly the commercial and industrial sectors and higher income groups. The penetration of agricultural insurance in developing countries is low despite its economic importance, with premiums accounting for only 0.01 percent of GDP. 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 (Hellmuth *et al.*, 2009).

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 *et al.*, 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 local 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 *et al.*, 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 *et al.*, 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 *et al.*, 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 (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) describes a number of ways in which insurers themselves can help to promote adaptation through risk communication and financial incentives.

5.5.3. Adaptation as a Process

Experience in planning and implementing adaptation to climate change as well as disaster response reveals that socio-institutional processes are critical in bringing together a set of inter-twined elements (Downing and Dyszynski, In press; Tschakert and Dietrich, In press)). O'Brien *et al.* (2011) suggest an adaptation continuum (see Figure 5-2), where the goal is to move towards partnerships that enable social transformations and increased resilience. Throughout the process, learning is expected to increase along with institutional change leading to the potential for paradigmatic transformation—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 5-2 HERE:
Figure 5-2: 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 *et al.*, 2006; Pelling *et al.*, 2008). Participatory learning is especially emphasized (Berkhout, 2002; Shaw *et al.*, 2009b; Shaw *et al.*, 2009a)(Berkhout, 2002; Shaw *et al.*, 2009b; Shaw *et al.*, 2009a; Shaw *et al.*, 2009a). 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, 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 questions about social and economic adaptation, and the information and data to support it, especially at the local scale (Cutter, 2001; Mileti and Peek, 2002; Mileti, 1999). For example: How do cumulative impacts of smaller events over time compare to single high impact events for localities? Do increased levels of hazard mitigation and disaster preparedness increase local risk taking by individuals and social systems? How do short-term adjustments or coping strategies enable or constrain long-term vulnerabilities in localities? What are the tradeoffs among decision acceptability versus decision quality, especially within local contexts (Comfort *et al.*, 1999; Travis, 2010)?

For many of these questions, sufficient empirical information is lacking, especially at the sub-national scale. A case in point is the lack of sub-national data on the local pattern of losses for disasters (see also section 5.4.2.3). There are few consistent databases for monitoring mortality from natural hazards at the local level (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).

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, and storms. 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 (Mitchell, 1988; Mitchell, 1999; Thomalla *et al.*, 2006; Van Aalst *et al.*, 2008)?

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 (Fischhoff, 2007; Pulwarty, 2007). 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 (Bullock *et al.*, 2009; Comfort *et al.*, 1999; McKinsey Group, 2009) have identified key research and data requirements for addressing these challenges, including designing and 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 research goal is to improve the assessment and transparency of risk in a geographic place-based approach for vulnerable regions. Improving the collection and quality control of locally-based data on economic losses, disaster and adaptation costs, and human losses (fatalities) will ensure improved empirically-based baseline assessments.
2) Develop maps of the decision processes for disaster mitigation, preparedness, response and recovery and guidance for using such decision support tools. Hazard maps developed through collaboration between researchers and affected communities 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 many aspects of disaster risk management including disaster risk reduction, risk-based pooling of resources, 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, 1993).
3) People who face hazards often need assistance to manage their own environments over the long term and develop systematic actions to improve resilience in vulnerable localities. Research is needed on how local governments and institutions can support, provide incentives, and legitimize successful approaches to increasing capacity and action.
4) Methodologies, indicators, and measurement of progress in reducing vulnerability and enhancing community capacity at the local level are under-researched at present. Locally-based risk management, cost-effectiveness methodologies and analyses, quantification of societal impacts of catastrophic events at local to national scales, and research on implementation and evaluation of risk management and mitigation programs are 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 and interventions especially at the local scale.
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, risk-based resource pooling and 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). Most studies had to rely 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. Disaster risk management and climate change adaptation strategies must address the underlying practices that contribute to vulnerability. One goal is to be clearer about existing conditions and projected changes in support systems and services e.g. weakening of bridges, levees and other structures due to long exposure to water of changing quality and other corrosives, or the decline of upstream watershed conditions that affect the livelihoods of downstream communities. 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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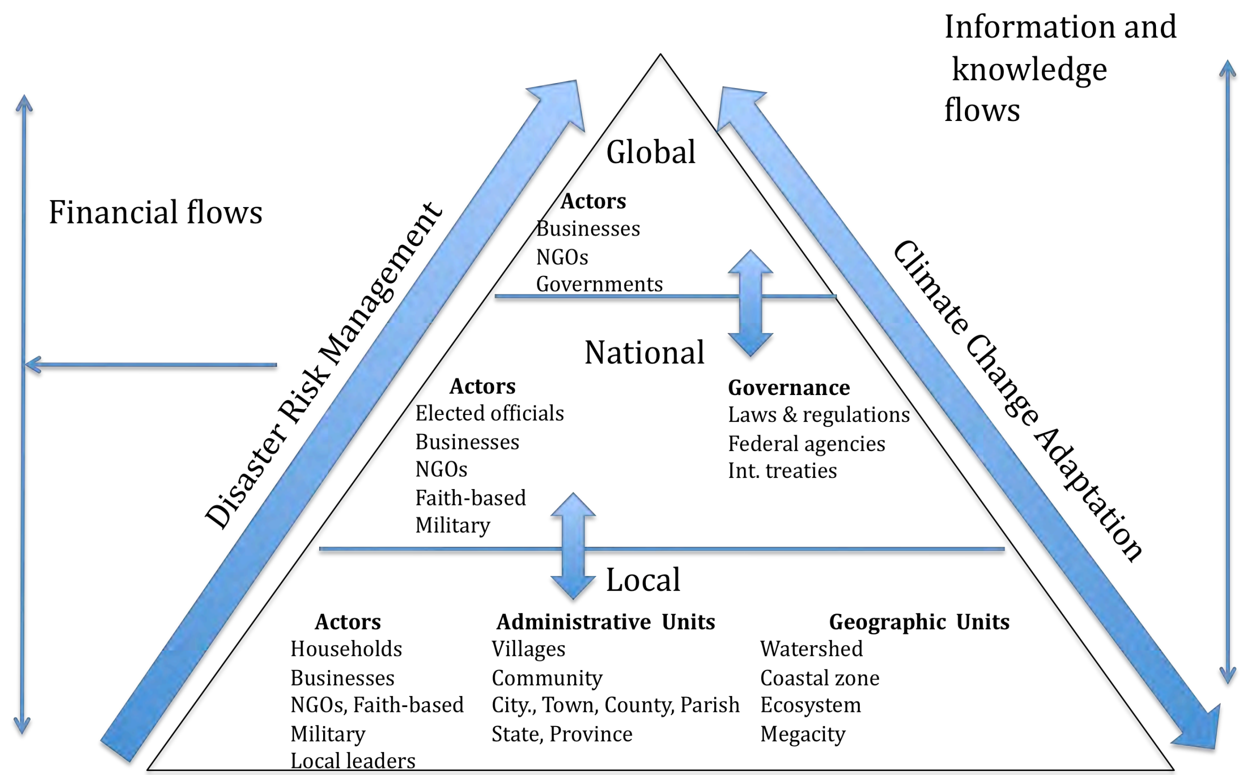

Figure 5-1 Linking local to global actors and responsibilities

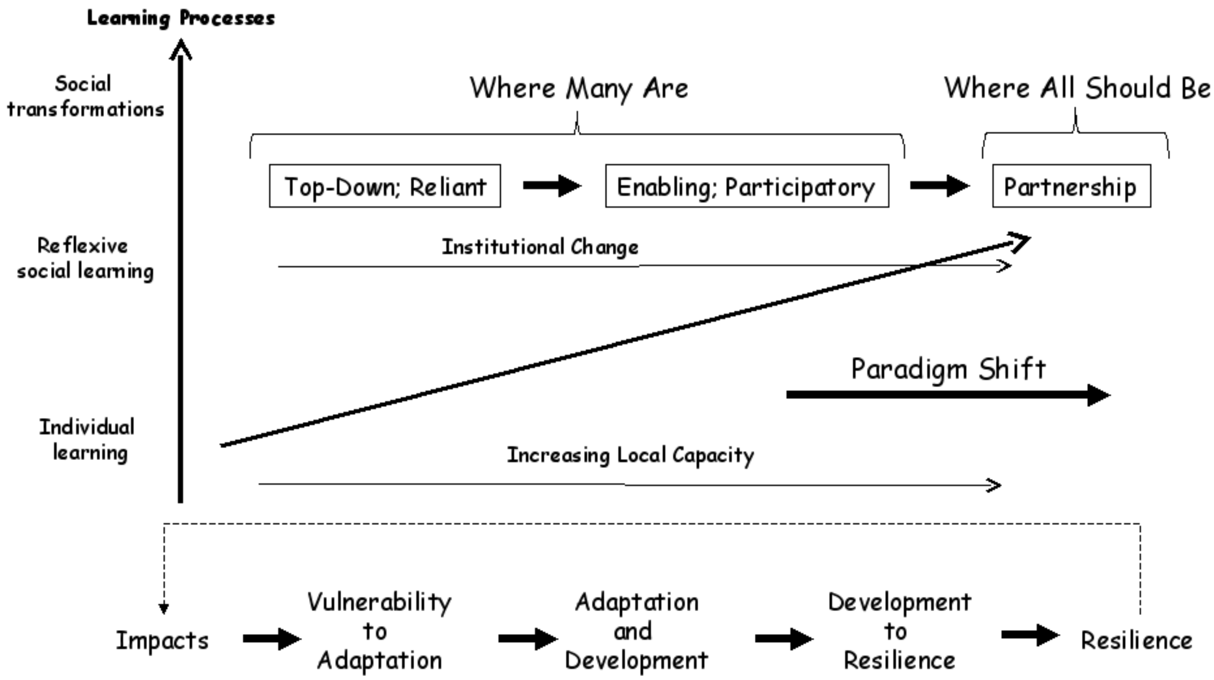

Figure 5-2: Dimensions of the adaptation continuum (O'Brien et al. 2009).

Chapter 6. National Systems for Managing the Risks from Climate Extremes and Disasters

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Contents

6.5. Knowledge Gaps

Frequently Asked Questions (FAQs)

References

Executive Summary

Disasters cause significant socioeconomic impacts in all countries, but low and middle-income countries are especially vulnerable, and experience higher fatalities and higher direct economic losses (high confidence). Disasters can be important barriers for continued socioeconomic development (medium confidence). Low and middle-income countries are especially vulnerable, and experience higher fatalities even when exposed to hazards of similar magnitude. The number of deaths per cyclone event, for example, in the last several decades was concentrated in low-income countries even though a higher proportion of population exposed to cyclones live in countries with higher income. While in absolute terms, the direct economic losses from disasters are greater in high-income countries, low-income countries bear the heaviest burden of these costs in terms of damage relative to annual GDP. In small exposed countries. particularly, small island developing countries, these wealth losses expressed as a percentage of GDP (but not a loss of GDP itself) can be very high, with recent assessments suggesting that the average costs over recent decades can be close to 10% for countries such as St. Lucia or Grenada and individual events can amount to more than 200% of annual GDP. Disasters can cause adverse developmental effects in causing hardships and even forcing people below the poverty line, and 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. Amongst the reasons influencing their ability to adequately respond to disasters include a lack of disaster insurance and other risk financing instruments, reduced tax bases, and high levels of indebtedness, combined with limited household income and savings, little capital assets and limited social insurance (6.1).

Effective national systems for managing the risks of disasters and extreme events involve actors playing differential but complementary roles according to their accepted functions and capacities, working in partnership across levels of society, temporal and spatial scales (high confidence). Actors include national and sub-national governments, civil society and community-based organizations, bilateral and multilateral agencies, research agencies, media and the private sector, working in partnership to cost effectively support efforts to reduce vulnerability and exposure to hazards. National and sub-national government agencies play multiple roles by initiating and leading many functions of the system: developing policies and strategies, enacting legislation and regulatory measures, deciding on risk financing and transfers and creating the enabling environments for other stakeholders in the system to flourish (6.2).

Advances in disaster risk management at national scale offer lessons for organising national systems for adapting to climate change (high confidence). Managing disaster risk at national level involves a continuum of actions and policy options that are complimentary and include measures to manage uncertainty, reduce risk, transfer and share residual risk and prepare for and respond to disaster impacts. The relative emphasis placed on different actors and actions depends on the scale of potential impacts, the capacities of governments or agencies to act, comparative advantage of community based organizations, the level of certainty about the future, the timeframes associated with predictions and the costs and political consequences of decisions. A sample of lessons across this continuum includes that:

- Efforts to systematically manage risk are more likely to be successful if they are co-ordinated across sectors and scales and led by organisations at the highest political level.
- Efforts to systematically manage risk are more likely to be successful if focus is also placed development-risk reduction-risk management as a continuum and risk considerations are integrated into economic development and environmental management efforts as well as well focused on disaster response and management.

- Legislation for managing disaster risks is most valuable where it is complemented by clear regulations that are effectively enforced across scales and complemented by other sectoral development and management legislations where risk considerations are explicitly integrated.
- Making informed decisions about which policy options to pursue is strongly dependent on comprehensive national databases of observations, losses, forecasts and inventories of assets and socio-economic information, and capacity for risk assessment and management..
- Ecosystem-based investments, including conservation measures associated with forestry, land use, coastal wetlands and biodiversity, offer benefits for reducing disaster risk across multiple sectors, as well as provide other livelihood benefits.
- While financial and economic planning for disasters has been often ignored in the recent past, a number of countries have begun to plan and budget for extreme events.
- A common recourse for financing residual risk involves disaster risk insurance and setting up reserve funds or contingent credit instruments and insuring public disaster relief expenditure, such as in the cases of Mexico or in the Caribbean.
- Early warning systems are only effective if they place emphasis on translating complex scientific information and engaging with target audiences and encompass four interacting components: (i) generation and management of risk knowledge including monitoring and forecasting, (ii) surveillance and warning services, (iii) dissemination and communication and (iv) response capability (6.3).

While the Hyogo Framework for Action has been influential in improving national systems, measures to manage current disaster risks and extreme events at national level are not sufficient to prevent increases in adverse impacts on human and natural systems (high confidence). Existing climate-related disasters are partially attributable to weaknesses in the national systems, including gaps in national public policies, poor co-ordination in national systems and to sub-optimal risk management at multiple scales. However, there is high confidence that improvement in risk management at national level, through better co-ordination, rigorous risk assessment, enhanced early warning systems, investments in human development, critical infrastructure and natural capital, and adequate financing, can significantly reduce impacts, including economic losses, morbidity and mortality (6.3).

The trends in hazards, vulnerability and exposure detailed in Chapters 2-4 present new challenges for disaster risk management. The effectiveness of current and future efforts to manage disaster risk at national level are therefore dependent on the extent to which they respond to these trends and integrate knowledge about dynamic risks associated with climate change (high confidence). The assessment found very limited evidence of cases where national disaster risk management systems and associated risk management measures had explicitly responded to the impacts of climate change on disaster risk. While the risk management literature indicates concern that climate change is increasing the frequency and magnitude of hazards, is increasing uncertainty and may be responsible, at least in part, for upward trends in disaster impacts, adaptive actions to these changes still tend to remain normative. The literature suggests that national systems for managing disaster risk can adapt to a changing climate by assessing and ‘mainstreaming’ knowledge of dynamic risks on a regular basis, respond to uncertainty by linking learning and adaptive management practices across scales, improve co-ordination between disaster, climate and development organisations, increase standing emergency response capacity and pursue efforts to address the root causes of poverty and other drivers of vulnerability (6.3, 6.4).

While disaster risk management actions need to be reassessed based on observed and projected hazard, vulnerability and exposure trends, there is considerable overlap between current disaster risk management and climate change adaptation measures that can be considered as ‘no or low regrets’ at the national level (high confidence). No or low regrets measures offer benefits with or without climate change and tend to be overlapping risk management and adaptation practices associated with addressing vulnerability and exposure. The assessment considered such ‘no or low’ regrets options across a range of key sectors, with some of the most commonly cited measures associated with improvements to early warning and health surveillance systems, improvements to sanitation and drainage systems, investments in national water conservation measures, enhanced education and training, maintenance of existing infrastructure, enforcement of building codes and restoration of degraded ecosystems and investment in nature and natural systems (6.3.1).

6.1. Introduction

The socioeconomic impacts of disaster events can be significant in all countries, but low and middle income countries are especially vulnerable, and experience higher fatalities even when exposed to hazards of similar magnitude (UNISDR 2009; IFRC 2010). The number of deaths per cyclone event, for example, in the last several decades was concentrated in low income countries even though a higher proportion of population exposed to cyclones live in countries with higher income; 11 percent of the people exposed to natural hazards live in low human development countries, but they account for more than 53 percent of the total recorded deaths resulting from natural disasters (UNDP 2004). At the same time, while in absolute terms, the direct economic losses from disasters are greater in high-income countries when compared to low-income countries, low-income countries bear the heaviest burden of these costs in terms of damage relative to annual GDP (UNDP 2004; DFID 2005), where this ratio overall amounted to 0.5% averaged over disaster and non-disaster years the 25 year period from 1980 to 2004 compared to 0.15% of GDP for high income countries. In small exposed countries. particularly, small island developing countries, these wealth losses expressed as a percentage of GDP (but not a loss of GDP itself) can be considerably higher, with recent assessments suggesting that the average costs over disaster and non-disaster years recent decades can be close to 10% for countries such as St. Lucia or Grenada (World Bank/UN, 2010). The average costs during disaster years can be much higher, for example in the Samoa these have been reported to be as high as 45.5% as compared with 6.7% across disaster and non-disaster years (Betterncourt et al 2006). Costs of individual events though can be almost 200% of the annual GDP as experienced in Niue following cyclone Heta in 2004 (McKenzie et al. 2005).

A growing body of literature has shown significant adverse macroeconomic and developmental impacts of natural disasters (Cochran 1994; Otero and Marti 1995; Benson 1997; Benson 1997; Benson 1997; Benson 1998; Benson et al. 2001; Benson et al. 2001; ECLAC 2002; ECLAC 2003; Murlidharan and Shah, 2001; Crowards, 2000; Charveriat 2000; Mechler, 2004; 2009; 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. Individuals, communities and even governments in developing countries often do not have sufficient capital to replace or repair damaged assets and restore infrastructure and livelihoods following major disasters. Amongst the reasons influencing their ability to adequately respond to disasters include a lack of disaster insurance and other risk financing instruments, reduced tax bases, and high levels of indebtedness, combined with limited household income and savings, little capital assets and limited social insurance. This body of evidence emphasises that natural disasters can cause a setback for development, and even a reversal of recent development gains in the short- to medium-term. Poor development status of communities and countries further 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 (Owens et al. 2003; Lal 2010). Consequently, natural disasters are seen as barriers for development, requiring ex-ante disaster risk reduction policies that also targets poverty and development (eg. Ninno et al. 2003; Owens et al. 2003; Skoufias 2003; Benson and Clay 2004; Cardona et al. 2010; IFRC 2010). There is though some literature that suggests that disasters may not always have a negative effect on economic growth and development and for some countries disasters are regarded as rather a problem of, and not for development (Albala-Bertrand, 1993; Skidmore and Toya 2002; Caselli and Malthotra 2004; Hallegate and Gill 2007).

As a response to the impacts of disasters on countries' economies, on levels of poverty and broader development trajectories, national disaster risk management systems have evolved in recent years, guided by international instruments, particularly the Hyogo Framework for Action 2005-2015 (see Chapter 7). Increasing knowledge, understanding and experiences in dealing with natural disaster risks and poverty has gradually contributed to a paradigm shift globally; a shift that recognises the importance of reducing risks and adaptation to climate change and as well as responding to and rebuilding after disaster events (Yodmani 2001; IFRC 2004; UNISDR 2004; UNISDR 2007; UNISDR 2008; Venton and LaTrobe 2008; IFRC 2010).While governments cannot act alone, majority of them are well placed and equipped to support communities and private sector to tackle disaster risk. It is at national level that overarching development policies and legislative frameworks are formulated and implemented to create appropriate enabling environments to guide other stakeholders to reduce, share and transfer risks (Carter 1992; Freeman et al. 2003), albeit in different ways. National level governments in developed countries are often the "insurers of last resorts" and used to be considered to be the most effective insurance instruments of society (Priest

1996). Governments are often what citizens turn to particularly when they do not have their own savings to fall back on or cannot rely on family or other social support in times when the effects of disasters affect many communities at the same time. However, there is disagreement in the literature about reliance on national governments as the appropriate foundation for a comprehensive risk management program, as it draws away from local concerns and initiatives (Aalbala-Bertrand 1993). Those holding this view favor reducing natural hazard risk through community-driven projects and programs developed by nongovernmental organizations (cross check with chapter 5). In practice, targeted governments' policies and actions aimed at ex-ante poverty reduction and improvements in their economic livelihoods can also help communities reduce their disaster risks, and better cope with disaster events (Ninno et al. 2003; Owens et al. 2003; Skoufias 2003; McGray et al. 2007).

National level governments also have the ability to mainstream risks associated with climate variability and change into existing disaster risk management and sectoral development, policies and plans; albeit to differing degrees depending on their capacity. These include initiatives to assess risks and uncertainties, manage these across sectors, share and transfer risks and establish baseline information and research priorities (Freeman et al 2003; Prabhakar *et al*. 2008; Mechler 2004). Ideally, national level institutions are best able to respond to the challenges of climate extremes, particularly 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 are well placed to take a longer time perspective when making decisions and are amenable to better appreciate key uncertainties and risks associated with climate change (Priest 1996; Hallegate and Gill 2007).

With this in mind, valuable lessons for advancing adaptation to climate change can be drawn from existing national systems for managing current disaster risks. These systems are comprised of actors operating across scales, fulfilling a range of roles and functions, guided by an enabling environment of institutions, international agreements and experience of previous disasters (Carter 1991; Freeman et al 2003). 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 (Cardona et. el 2010). 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 (Lavell 1998; McGray et al. 2007; Venton and La Trobe 2008)

Closing the current adaptation deficit 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 climatic extremes, a stronger institutionalisation across scales and levels of governance, a greater number of experienced actors and more widespread instances of supporting legislation and cross-sectoral co-ordinating bodies, national disaster risk management systems offer a promising avenue for supporting adaptation to climate change and reducing climate-related disaster risks. In many cases, it is at this national level that national systems for adapting to climate change and changing disaster risks, where policies themselves adapt to changing conditions, will provide a critical supporting environment for adaptation processes at all scales. Development of adaptive policymaking will require policymakers to treat policies as ongoing experimental and learning processes (McGray et al. 2007).

However, despite some recent progress in strengthening national systems, and despite the burden of disasters imposed are increasingly being recognized, measures to reduce the risks of disasters are still small, and for most part there is a continued reliance on post disaster response and disaster management support. While it is difficult to accurately indicate the level of funds allocated to disaster risk reduction efforts as compared to disaster response and rehabilitation efforts, major donors and international financial institutions, such as the World Bank, SIDA, and European Union in 2003 reported to have at times allocated in excess of 90% of their disaster management funds for relief and reconstruction and less than 10% of the funds for preparedness and risk reduction (LaTrobe and Venton 2003). This level of investment by government and development partners in preventing disasters can be partially explained inter alia by a difficulty in mainstreaming disaster risk management in all phases of national development due to a lack of understanding and knowledge and concrete evidence regarding the types and extent of the cost and benefits of measures to reduce disaster risk as compared with disaster management (LaTrobe and Venton 2003; Benson and Twigg 2004).

Costs and benefits information on disaster risk reduction and adaptation options could help motivate and defend investments in these measures. Some recent studies on sub-national level disaster risk reduction and adaptation measures have demonstrated that disaster prevention and adaptation can pay high dividends. Several studies (Mechler 2005; MMC 2005; Moench et al. 2007; UN/ World Bank 2010) reported that for every dollar invested in risk management broadly, two to six 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, and in the presence of limited budgetary resources, many policy makers have been reluctant to commit significant funds for risk reduction. Many international agencies also continue to invest considerable funds into high profile, post-disaster response particularly when these are reported in media stories (LaTrobe and Venton 2003; Benson and Twigg 2004).

While there is current lack of emphasis on risk reduction compared to response, there are nevertheless many success stories and promising initiatives for managing and reducing the risks of climate extremes and disaster that could provide valuable guidance for strengthening national systems for advancing adaptation to climate change.

Accordingly, this chapter assesses the literature on national systems for managing disaster risks and climate extremes, particularly the design of such systems of functions, actors and roles they play, emphasising the importance of government and governance for improved adaptation to climate extremes and variability. It reflects on the adequacy of existing knowledge, policies and practices globally and considers the extent to which the current disaster risk management systems may need to evolve to deal with the uncertainties associated with and the effects of climate change on disaster risks. 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 agencies, 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 desirable in an effective national system for adapting to climate change and what gaps in knowledge exist. The later part of the chapter is organised by the set of functions undertaken by the actors discussed in 6.2. The functions are 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) for reducing climatic risks. 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 and the impacts of climate change on vulnerability and poverty. 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 a concern of multiple actors, from national and sub-national governments, private sector, research bodies, civil society and community-based organizations and communities working in partnership to ultimately help individual households to reduce their risks and vulnerabilities (Twigg, 2004, UNISDR 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 spatial and temporal scales, supported by relevant scientific and traditional knowledge (UNISDR, 2008). This section assesses the literature on 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 socio-natural disasters (UNISDR, 2004). 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 (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 is expected for them to govern and regulate risks owned by other parts of society (Mechler, 2004).

Recourse to various normative theories could be included. 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, Twigg, 2004; White *et al,* 2004; McBean, 2008; Shaw *et al,*2009). The risks faced by governments include losing public infrastructure and assets. National level government also redistributes 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 become poor, 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 are expected 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 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; UNISDR, 2004; Christensen *et al*., 2007; UNISDR, 2009).

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 them. 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 (UNISDR, 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 provides 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; Twigg, 2004; Handmer and Dovers, 2007; CCCD, 2009). Resources must be available at all administration levels, but not sufficient policy and institutional commitment has been made to provide adequate resources at al level, especially in local governments (Twigg, 2004; UNISDR, 2009). The funds could be used in a complementary manner to address adaptation deficit, sustainable development and disaster risk reduction. 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.

6.2.2. Private Sector Organisations

Some aspects of disaster risk management may be suited for non-government stakeholders to implement, albeit this would most effectively be coordinated within a framework created by governments. The private sector plays an important role in DRM and adaptation. Three avenues for private sector engagement may be identified (Roeth, 2009; UNISDR, 2008): (i) corporate social responsibility (CSR) in terms of advocacy and general awareness raising for DRR and involving funding support and the contribution of volunteers and expertise, (ii) Public Private Partnerships (PPP) enhancing the provision of public goods for DRR in joint undertakings of public and private sector players, and (iii) businesses model approaches. While a considerable amount of effort has been dispensed on CSR, PPPs and business model approaches remain rather untouched areas, one very important exception being risk financing and insurance.

Risk financing instruments in 2010 covered about 40% of disaster losses in exchange for premium payments, this albeit mostly in the industrialized countries (Munich Re, 2010). In developing countries, despite complexities and uncertainties involved on both supply and demand for risk transfer, risk financing mechanisms have been found to demonstrate substantial potential in 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 et al., 2005; Cummins and Mahul, 2008; Hazell and Hess, 2010). There is some uncertainty as to the extent to which the private sector would continue to play this role in the context of changing environment 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 less prepared to underwrite insurance for extreme event risks linked to climate change due to ambiguity aversion, i.e. the uncertainty about the chances of climate change induced modifications of extreme event intensity and frequency). Thus innovative private-public sector partnerships are required supported in developing countries by development partner funds as well (see section 6.3.3.3 *and case study in chapter 9).*

Although the potential for private sector players in DRR in sectors such as engineering and construction, information communication technology, media and communication as well as utilities and transportation seems large (Roeth, 2009), little evidence of successful private sector activity has been documented here, owing to a number of reasons: there has in fact been little cooperation and activity as the business case for private sector involvement in DRR remains unclear, hampering private sector engagement; companies may be averse to reporting activities which are fundamental to their business; and, in more community-focussed projects companies often work with local non-governmental organizations and do not report those efforts. Climate change seems to be an entry point here as well leading to an enhanced understanding of a business case in DRR particularly in terms of guaranteeing global value chains in the presence of potentially large scale disruptions triggered by disasters. As one example, the economic viability of the Chinese Coastal Zone, the economic heartland of China and home to many multinational companies producing a large share of consumer goods globally while at the same time highly exposed to typhoon risk, increasingly will depend on well implemented DRR mechanisms in terms of PPP and core business efforts (Roeth, 2009).

6.2.3. Civil Society and Community-Based Organisations (CSO and CBOs)

At the national level civil society and community based organizations have gained a major role in developing different initiatives to respond to disasters, reduce the risk of disasters and, recently, adapt to climate related hazards. CSO and CBO initiatives in the field of disaster risk management while may usually begin as humanitarian concerns, 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; SEED 2008; Tearfund 2008; World Vision 2008).

Recently in some high risk regions there has been a large development of national platforms of CSO and CBO that have been working together in order to push for the transformation of policies and practices related to disaster risk reduction, this is specially true in the case of Central America, where at least four platforms are functioning in the same number of countries, gathering more than a hundred and twenty CSO and CBO’s (CRGR, 2007). In recent times the efforts of these platforms have been aimed to advocacy, training, research and capacity building in DRR. Advocacy on climate policy construction has been included as a new set of activities since 2007 (CRGR, 2008). In other cases, like in South America CSO have been developing efforts aimed at the local level, trying to link disaster risk reduction with local development goals (Lavell, 2009), as a matter of fact in most of the cases CSO are developing actions at the local level, emphasizing in different services such as water, sanitation, irrigation, social infrastructure or disaster preparedness (GNDR, 2009).

Civil society organizations and Community-based organizations 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 (UNISDR 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 several countries of Latin America CSO and CBO are considered, by law, as part of the national systems for civil protection, this is the case.(CRGR, 2007a., Lavell and Franco, 1996). Among the biggest challenges for civil society organizations the following can be mentioned: securing resources for replicating successful initiatives and scaling up geographically (Care International 2008; Oxfam America 2008; Practical Action Bangladesh 2008; SEED 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 (Oxfam America 2008), and coordinating and linking local level efforts with sub-national government initiatives and national plans during the specific project implementation (SEED 2008).

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, 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 (UNISDR, 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. Even a progress has been reported in the communication and availability of scientific information, still a lack of for example sufficient local or sub-national data of hazards (UNISDR, 2009).

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 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; (d) been actively engaged in technical capacity building and training; (e) translating scientific evidence into adaptation practice; (f) collating traditional knowledge and lessons learnt for wider dissemination, and (g) translating scientific information into user-friendly forms for community consumption (Sperling and Szekely 2005; Thomalla et al. 2006).

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 (Sperling and Szekely 2005; Thomalla et 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 governments are usually expected to lead the management of disaster risks and that governments typically have the greatest potential for delivery and implementation.

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 usually have the mandate and capacity to create the enabling environment for other actors through its own agencies to reduce risk, share and transfer residual risk and manage the impacts of disasters. By drawing upon 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 activities 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 (UNISDR, 2009; CCCD, 2009). 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, in mainstreaming climate change adaptation and disaster risk management into plans, policies and processes for development and in securing additional financial and human resources needed to meet increasing demands (UNDP, 2002; CCCD, 2009;

Schipper, 2009). 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 and sub-national 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, the timeframes within which these future impacts and disasters will occur and the costs and consequences of decisions that play an important role in their prioritization and adoption (Heltberg et al, 2008; World Bank, 2008b).

Both DRR and CCA have a common goal of risk reduction, with DRR concerned with an ongoing problem (disasters) and CCA more concerned with an emerging climate change issue (McGray et al, 2007; WRI, 2007; UNISDR, 2009). Similarly, both DRR and CCA are best mainstreamed or implemented through other sectors and other policies, including those for agriculture, water resources, infrastructure, health, land use, environment, early warning services, finance and planning (UNISDR, 2009). Both are also linked with other plans, policies and strategies for poverty eradication, planning for sustainable development, education and use of hydro-meteorological science (WRI, 2007; UNISDR, 2009).

There is a continuum of national planning and policy options that can be used to implement (or mainstream) DRR and CCA actions. The options range from climate vulnerability approaches through to climate change impact-based approaches. On the left hand side of the continuum, the vulnerability oriented CCA options overlap with existing DRR practices and realize “no regrets” benefits, with or without climate change. These vulnerability-based approaches are described in Chapters 2 and 4. At the far right side of the continuum are the specialized climate change science dependent activities that exclusively target and reduce distinct climate change impacts. Many of these climate science based approaches are described in Chapter 3. In between the ends of the continuum lie a broad spectrum of activities with gradations of emphasis on vulnerability and impacts. In some cases, mal-adaptation can occur when vulnerabilities to the current climate are addressed without consideration of climate change impacts (e.g. changes to agricultural livelihoods to strengthen resilience today could undermine DRR gains over the longer term when climate change impacts on future flood risks are ignored). Maladaptation actions are discussed in detail in section 1.4.

Increasingly, studies suggest that the most pragmatic CCA and DRR options depend on the adaptive capacity and ability of the country or sector to deal with uncertainties (McGray et al, 2007; Wilby and Dessai, 2010; Auld, 2008b; UNISDR, 2008; Lu, 2009). Cases where certainty is greater in projecting future climate change impacts may better lend themselves for the “top down” modelling approaches, while cases where adaptive capacity is low or the uncertainties over future climate changes are high may be more suited to the “no regrets” and vulnerability-oriented approaches (McGray et al, 2007; UNISDR, 2008; Auld, 2008b; Wilby and Dessai, 2010; Lu, 2009). No-regret approaches are little affected by uncertainties in the information on future climate changes and hence, can be justified under all plausible future climate change scenarios, including no climate change (i.e., they deliver benefits greater than costs no matter what happens to the uncertain parameters in the decision-making) (McGray et al, 2007; Eales et al, 2006; Agrawala and van Aalst, 2008; OECD, 2009; Prabhakar et al, 2009; Auld, 2008b). These no regrets actions would include interventions enhancing the provision and dissemination of climate information for agriculture in drought-prone regions or improving hazard warning and dissemination systems or updating climatic design information for engineering projects. At the other end of the spectrum, some long-term, high implication planning issues (e.g., to plan for the relocation of a large population) or large investments (e.g., a system of major infrastructure projects or watershed management) start with the current and future climate, involve climate change impacts studies and may also incorporate additional redundancies that account for the uncertainties of the future climate (Lu, 2009; McGray et al, 2007; Wilby and Dessai, 2010). Given the consequences, the high irreversibility of the decisions, the significant investment costs and the long-lived nature of these national decisions, more climate information may be needed to treat the range of uncertainties for the future.

Some CCA and DRR options involve "win-win" outcomes for greenhouse gas reduction, disaster risk management, climate change adaptation and development synergies (Heltberg et al, 2009; Ribeiro et al, 2009; World Bank, 2008b). Many of the "win-win" options, illustrated in Table 6-1, include ecosystem-based adaptation actions, sustainable land and water use planning, carbon sequestration, energy efficiency and energy and food self-sufficiency. An example would include afforestation, reforestation and conservation of forests for disaster risk reduction from floods, landslides, avalanches, coastal storms and drought while contributing to adaptation for future climates, economic opportunities, increased biomass and carbon sequestration.

[INSERT TABLE 6-1 HERE:
Table 6-1: National policies, plans, and programs: selection of disaster risk management and adaptation options.]

Under both current and future climate conditions, disaster risk sharing is another viable option and includes instruments 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, can 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). The catastrophe insurance pool in Turkey for flood risks, as illustration, offers incentives for improved standards and thereby can mitigate climate risks (von Lucius, 2004, Hoff et. al, 2005). The decision to "bear residual losses" is also an option when uncertainties over the directions of future climate change impacts are high, when capacity is initially limited or adaptation options not available or when the risks of future impacts are considered to be very low (Linnerooth-Bayer and Mechler, 2006; Heltberg et al, 2009; World Bank, 2010). Residual losses are also the reality when very unusual events—well beyond those typically expected—result in exceptionally high impacts. All of these policy and planning options are particularly relevant at the sectoral level where governments either define enabling environments for development projects or define risks that are shared or transferred to different parts of society.

It is important that uncertainty over future climate change risks not become a barrier to climate change risk reduction actions. In cases where climate change uncertainties will remain high, countries may choose to increase or build on their capacity to cope with uncertainty, rather than risk maladaptation from use of ambiguous impact studies or no action (McGray et al, 2007; Lu, 2009). National policies may need to become more adaptable in cases where national plans and policies operate within a limited range of conditions and are oriented towards providing certainty (McGray et al, 2007; UNISDR, 2008). Without flexibility, rigid national policies may become disconnected from evolving climate risks and have unintended consequences (Sperling and Szekely, 2005).

6.3.1.2. Mainstreaming Disaster Risk Management and Climate Change Adaptation into Sectors and Organisations

Mainstreaming of CCA and DRR implies that national, sub-national and local authorities adopt, expand and enhance measures that factor disaster and climate risks into their normal plans, policies, strategies, programs, sectors and organizations (CCCD, 2009; Few et al 2006; UNISDR, 2008). In reality, it can be challenging, even for experts within the fields of CCA and DRR, to provide clear pictures of what mainstreaming is, let alone how it can be made operational, supported, and strengthened at the various national and sub-national levels (Olhoff and Schaer, 2010). The real challenge to mainstreaming adaptation is not planning but implementation.

The existing barriers to managing the disaster risks from current climate variability may need to be addressed in order to reduce the even greater barriers that inhibit actions nationally towards future climate disaster risks (UNDP, 2002; UNDP, 2004); CCCD, 2009; Prabhakar et al, 2009). A key challenge, and an opportunity in mainstreaming DDR and CCA lies in building bridges between current disaster risk management actions to deal with existing climate vulnerabilities and the additional and revised efforts needed for adaptation to future climate change (Few et al, 2006; Olhoff and Schaer, 2010). The DRR community has a long tradition in multi-disciplinary, vulnerability and community-based approaches to reducing risks, often based on response to events, while the CCA community has traditionally placed emphasis on atmospheric prediction science, technological advances, monitoring, warning-response-relief approaches or in the longer term, on climate change modelling and potential impact reductions (Thomalla, 2006; Basher, 2009). As a result, CCA approaches to date have been predominantly "top-down" or information cascading processes, but with limited tangible examples of planned adaptation decisions being based on these approaches (Wilby and Dessai, 2010; UNISDR, 2008). On the other hand, most disaster risk management planning has traditionally aimed to reduce disaster risks from existing climate hazards and vulnerabilities, sometimes little appreciating that the future may not be a repetition of the past uncertainties, hazards and risks (Dilley, 2005, Prabhaker et al, 2009). The DRR community also has a long tradition and strength in multi-disciplinary, vulnerability and community-based approaches to reducing risks Inherent in the bridge building is a need to better understand how existing DRR practices need to be augmented or revised for future adaptation. Some studies advocate a concurrent or twin-track approach to mainstreaming CCA and DRR, consisting of: (1) "bottom-up" approaches or vulnerability assessments of social and economic strategies for coping with present climate extremes and variability, as practiced by the DRR community and (2) "top-down" approaches using climate forecast tools and scenarios to evaluate sector-specific, incremental changes in risk over the next few decades (Wilby et al, 2009; Wilby and Dessai, 2010; Auld, 2008b; Schipper, 2009). In many cases, the approaches can be combined and "streamlined" by considering a range of climate change scenarios and impacts relative to critical vulnerability thresholds defined by decision-makers (Wilby et al, 2009; Auld, 2008b; McGray et al, 2007). The combination of 'top-down' and 'bottom-up' thinking allows vulnerability and impacts approaches to be "mixed and matched" for the realities of different geographic scales, uncertainties and governance mechanisms. In some cases, changing climate risks can be monitored and mainstreamed into decision-making through regularly updated revisions to hazard and vulnerability assessments (Prabhakar et al, 2009; Dilley 2006). Redundancies can also be incorporated into existing disaster management planning in order to strengthen against the unforeseen risks of the changing climate (Prabhakar et al, 2009; McGray et al, 2007). In other cases, downscaled ensembles of future climate change and socio-economic scenarios, impact models, vulnerability assessments and their uncertainties can be incorporated or mainstreamed into planning (Wilby and Dessai, 2010; Wilby et al, 2009; Prabhakar et al, 2009).

In reality, limitations on the availability of current climate hazards and risk information, a mismatch between climate model outputs and the information needs of adaptation planners, limited access to dependable high-resolution regional climate change projections, a shortage of good quality climate data and methodologies for downscaling relevant climate variables to decision-making scales, uncertainties in the climate scenarios themselves, limitations in the relevant climate parameters available from existing models, and a shortage of guidance on the contributions that climate hazards alone make to risks all limit mainstreaming actions (Prabhakar et al, 2009; Basher, 2009; Wilby, 2009; Auld, 2008b). Even when good quality climate risk information is available to meet needs, there may be other factors, including political and economic realities, that influence whether climate guidance is accepted for decision-making (UNISDR, 2008; WCC 2009, NTREE, 2009) . The scope for mainstreaming climate change scenario information into CCA and DRR planning depends on the risk management approach taken, the availability of technical and financial capacity, scale of the risk(s) and the type(s) of adaptation being considered (Adger et al., 2005; Dessai et al., 2005; Wilby et al, 2009).

Much of the guidance and tools used for mainstreaming tends to be tailored for decision-making at the local, regional and project level, rather than the sectoral and national level (Few et al, 2006; Olhoff and Schaer, 2010). Generally, studies indicate that the most effective means for effectively mainstreaming both DRR and CCA nationally involve "whole of government" coordination across different levels and sectors of governance and include the involvement of a broad range of stakeholders (Few et al, 2006; Thomalla et al, 2006; OECD, 2009). In spite the strong interdependencies, governments have tended to manage these issues in their "silos". Typically, environment or energy authorities as well as scientific institutions have tended to be responsible for climate change adaptation while disaster risk management authorities may reside in a variety of national government departments (Prabhakar et al, 2009; Thomalla, 2006; Sperling and Szekely, 2005). Progress within government agencies usually depends on political commitment, institutional capacity and in some cases, on enabling legislation, regulations and financial support (Few et al, 2006; OECD, 2009). Nationally, it may be important to clearly identify a lead for disaster and climate risk management efforts where that lead has influence on budgeting and planning processes (Few et al, 2006; OECD, 2009). In some cases, countries may be able to build on phases of raised awareness and increased attention to disaster risk in order to develop and strengthen their responsible institutions (Few et al, 2006).

While developed countries may be equipped to meet many of the challenges of mainstreaming adaptation and disaster risk reduction into national plans and policies, the situation is often much less satisfactory in developing countries (Basher, 2009). Nonetheless, there are examples from developing countries where progress is being noted in mainstreaming CCA and DRM, as shown in the Chapter 9 case studies. In other cases, international and national funding mechanisms such as the LDC (Least Developed Countries) Fund, the Special Climate Change Fund, Multi-donor Trust Fund (MDTF) on Climate Change, the Climate Investment Fund of the Pilot Programme for Climate Resilience (PPCR), are making funding and resources available to developing countries to pilot and demonstrate the integration of changing climate risks and resilience into core development implementation and providing incentives for scaled-up action and transformational change (see section 7.4.3 for details).

6.3.1.3. Developing Sector-Based Risk Management and Adaptation Approaches

National planning and policies can be challenged to manage short-term climate variability while also ensuring that different sectors and systems remain resilient and adaptable to changing extremes and risks over the long term (UNISDR, 2007; Füssel, 2007; Wilby and Dessai, 2010). The challenge is to find the balance between the short-term and the longer-term actions needed to resolve underlying causes of vulnerability and to understand the nature of changing climate hazards (UNFCCC, 2008; OECD, 2009). Achieving DRR and CCA while attaining human development goals requires a number of cross-cutting, inter-linked sectoral and development activities, as well as effective strategies within sectors and coordination between sectors (Few et al, 2006; Thomalla et al, 2006). Climate change is far too big a challenge for any single ministry of a national government to undertake (CCCD 2009).

In many countries, sectoral-based organizations and government departments play a central role in national decision-making and are a logical focus for adaptation actions (McGray et al, 2007). Table 6-1 provides examples of some sectoral CCA and DRR approaches that have been documented at the national scale, including governments, agencies and the private sector. These national level sectors and landscapes included in the table include natural ecosystem management, agriculture and food security, fisheries, forestry, coastal zone management, water management, health, infrastructure including housing, cities and transportation, and energy. As described above, the options in the table can be considered as a continuum of potential actions that are incremental and reinforce each other. The national DRR and CCA options for sectors are categorized in Table 6-1 as follows:

- Plans and policies to accept and deal with residual risks (e.g. can't adapt, unavoidable risks);
- Plans and policies to transfer or "spread" the risks due to current or future hazards;
- Climate proofing or "no regrets" plans and policies to reduce existing climate risks ;
- Plans and policies that prepare for the uncertainties associated with the future climate;
- Climate change adaptation plans and policies that reduce disaster risks from future climate change;
- "Win-win" plans and policies offering synergistic solutions for GHG reductions, climate change adaptation, disaster risk reduction and human development.

Several national level sectoral risk management and adaptation options, along with their challenges and opportunities, are described in the Chapter 9 case studies. In many of these case studies, the starting point for risk management and adaptation are the options that address existing vulnerabilities.

The impacts of changing climate risks in one sector can affect other sectors and scales, operating vertically and horizontally—vertically from national to local levels or scales within the same sector and horizontally across different sectors at the same level or scale (Urwin and Jordan, 2007; CCCD, 2009; UNFCCC, 2008). The complex and multi-disciplinary nature of these cross-sectoral impacts will require innovative national approaches (Urwin and Jordan, 2007). While the case and need for integration across sectors and levels may be clear, the issue of how to integrate or mainstream nationally across multiple sectors still remains challenging, requiring governance mechanisms and coordination that can cut across governments and sectoral organizations (UNFCCC, 2008; CCCD, 2009). Typically, multi-sector integration tends to deal with the broader national scale (e.g. entire economy or system) and aims to be as comprehensive as possible in covering several affected sectors, regions and issues (UNFCCC, 2008). Effective CCA and DRR coordination between all sectors may only be realized if all areas of government are coordinated from the highest political and organizational level (CCCD, 2009; Schipper and Pelling, 2006; Prabhaker, 2009; UNISDR, 2008).

CCA and DRR approaches for most sectors benefit from ecosystem based adaptation and integrated land, water and coastal zone management options. For example, conservation and management of ecosystems, forests, land use and biodiversity have the potential to create win-win disaster risk protection services for agriculture, infrastructure, cities, water resource management, food security, etc and also create synergies between climate change adaptation and mitigation measures (CCCD, 2009; CBD, 2009; UNISDR, 2009). Water resources management options cross or thread up and down different spatial scales and levels and policy options, from the local to the global and international and also require integrated approaches (CCCD, 2009; Urwin and Jordan, 2007). Water shortage due to climate induced drought will not only limit people's access to drinking water but also seriously affect a range of economic activities, ranging from farming to industry to energy production (CCCD, 2009; IPCC, 2007; WHO, 2003). However, adaptive agriculture and integrated coastal zone and water management practices may prove particularly important in managing water resources in light of climate change (CCCD, 2009; UNFCCC, 2008; IPCC, 2007; UN-WWAP, 2009). Human health will be impacted both directly and indirectly from the changing climate and public health planning and policies may need to shift from focusing only on relatively short-term risks to include the projected long-term impacts of climate change (IPCC, 2007; CCCD, 2009; World Bank, 2009; WHO, 2003). National energy systems are closely linked to adaptive capacity, GHG mitigation, disaster risk reduction, land and water use and human development—sometimes with competing objectives (Marcel and Kok, 2008; UNDP, 2005). Access to energy services and energy efficiency options will become increasingly important for countries and their development, given that the capacity of countries to adapt to climate change risks is much greater where access to energy supplies and energy efficiency options is greater (CCCD, 2009; Klein et al, 2007). The literature indicates that, traditionally, no country in modern times has substantially reduced poverty initially without an increase in its use of commercial energy and/or a shift to more-efficient energy sources that provide better energy services (CCCD, 2009; UNDP, 2005).

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). It is important to recognise the variation between countries in governance capacity for managing the risks and uncertainties of changing climate extremes. 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 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 (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 (UNISDR 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 (UNISDR 2005; Bhavnani et al. 2008), 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)

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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 (UNISDR 2005 *review of national submissions*), especially as experience suggests legislation should 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 (UNISDR 2005, Pelling and Holloway 2006).

Improving risk management legislation in the context of climate change suggests stronger synergy with economic development, land-use planning and environmental protection laws, and the integration of environmental management principles into existing legislation (UNISDR 2007, UNISDR 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 requires cross-sectoral coalitions. Evidence from the Philippines cited in Chapter 9, one of 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 (UNISDR 2007). Limited independent evaluations of National Platforms exist and conclusive evidence of their establishment leading to more effective disaster risk management is largely absent though strong in normative literature (UNISDR 2007).

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 [UNISDR GAR 2009], despite calls to involve climate change focal points/organisations into National Platforms (UNISDR 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) (see Box 6-2).

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Box 6-2. National and Sub-National Coordination for Managing Disaster Risk in a Changing Climate: Kenya Case Study

Kenya's National Platform sits under the Office of the President and has made significant achievements in co-ordinating multiple stakeholders, but is constrained by limited resources and lack of budgets for DRR in line ministries (Kenya Submission to Global Platform 2009). Key constraints of the national system are recognised as being difficulties in integrating DRR in planning processes in urban and rural areas and lack of data on risks and vulnerabilities at different scales (ibid 2009; Few *et al* 2006). In this regard, Nairobi has experienced multiple periods of drought and heavy rains in the last decade, prompting action to reduce exposure and vulnerability to what is perceived as changing hazard trends (ActionAid 2006). Increasing exposure and vulnerability has resulted from a rapid expansion of poor people living in informal settlements around Nairobi, leading to houses of weak building materials being constructed immediately adjacent to rivers and blocking natural drainage areas. While data and co-ordination systems are still lacking, the Government of Kenya has established the Nairobi Rivers Rehabilitation and Restoration Programme (ADB, Tunis 2010), designed to install riparian buffers, canals and drainage channels, while also clearing existing channels. The Programme also targets the urban poor with improved water and sanitation, paying attention to climate variability and change in the location and design of wastewater infrastructure and environment monitoring for flood early warning (ADB Tunis 2010). This demonstrates the kind of no or low regrets options for investments that can be achieved in the absence of a fully fledged nationally co-ordinated disaster management system and in the absence of complete multi-hazard, exposure and vulnerability data sets.

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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 (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; Linnerooth-Bayer, Pflug and Mechler, 2005; Hochrainer, 2006; Mahul and Ghesquiere , 2007; Cummins and Mahul, 2009). 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, 2009).

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 Polackova 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 (modified after Schick and Polackova Brixi, 2004).]

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, 2009; Linnerooth-Bayer and Mechler, 2007; see Box 6-3). 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.

_____ START BOX 6-3 HERE _____

Box 6-3. 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 remained a concern. 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

_____ END BOX 6-3 HERE ______

6.3.3. Practices including Methods and Tools

Governments, and other agencies working in the national system have developed a set of different practices for managing disaster risks. Practices involving risk assessment, information systems, hard and soft management options, risk transfer, public awareness, early warning, preparedness and response are all raised in this sub-section, which is divided into four sections related to those practices associated with building a culture of safety (6.3.3.1), reducing climate related risks (6.3.3.2), transferring and sharing residual risk (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 several strategies and activities that start with the assessment of risk factors and building information systems that provide relevant information for critical decision making. Early warning systems play a very relevant role in disaster management but, as stated in this section, also in long term planning because of their capability of generating relevant information of inadequate land use and planning, for example.in the same sense climate-adapted infrastructure, enhanced human development, ecosystems protection, risks transfer and sharing and managing the impacts of climate related disasters can play a fundamental role in building a culture and practice of human safety.

6.3.3.1.1. Assessing risks and maintaining information systems

As discussed in chapters 2 and 3, the first key step in managing risk is to assess and characterise it. In terms of risk factors, disaster risk commonly is defined by three elements: 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 is framed in the context of public perception and management needs (See Chapter 5).

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 (UNISDR, 2004; Prabhakar, 2008).

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, 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, 2009). In addition, risk management process would require identifying those elements of the social process that also contribute to vulernability – organisational and institutional strength, the status of national wealth and human development status of community at risk and capacity to respond to disasters (Cardona et al 2010 and Lavell 1998). Considerable progress has been made in the use of information (UNISDR, 2009). Nevertheless, in many countries this is not a regular practice and efforts to document impacts are started only after major disasters (UNISDRUNISDR, 2004; Prabhakar, 2008). Regular monitoring of vulnerability is also at nascent stage (Cardona, 2010;Dilley, 2005). 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 (adapted from Wilby, 2009).]

As to assessing and monitoring 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 (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 as 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).

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 and preparedness for disaster response. For this, a robust and up-to date Early Warning Systems (EWS) is critical to not only reduce or mitigate the impacts of disasters, but to also provide timely warning to the agencies involved in preparing for and 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). Traditionally, early warning systems had 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 received by or helpful to the population it serves or actually used to reduce risks (UNISDR, 2006; 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 (UNISDR, 2005; Auld, 2008a; Basher, 2006; Wimbi, 2007). To be effective and complete, an early warning system typically comprises four interacting elements (UNISDR, 2006a; Basher, 2006): (i) generation of risk knowledge including monitoring 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 (UNISDR, 2001; Auld, 2008). Warnings are received and understood by a complex target audience and are most relevant when conveyed to have meaning that is shared between those who issue the forecasts and the decision-makers they are intended to inform (Auld, 2008; Basher, 2006; UNISDR, 2006a). Because emergency responders, the media and the public often are unable to translate the scientific information on forecast hazards in warnings into risk levels and responses, early warning systems are most effective when they can identify and interpret the general impacts in simple and meaningful terms, 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; UNISDR, 2006a).

Different hazards and different sectors often require unique preparedness, warnings and response strategies (UNISDR, 2006a; Basher, 2006; van Aalst, 2009). Some may represent singular extreme events, sequences or combinations of hazards. For example, the World Meteorological Organization (WMO), National Meteorological and Hydrological Services, World Health Organization (WHO), Food and Agriculture Organisation (FAO) and other United Nation 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 heat waves and vector-borne diseases (WMO, 2007; UNISDR, 2006a) and early warnings of locust swarms (WMO, 2007; WMO, 2004b; FAO, 2011). 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, 2008a; 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 (UNISDR, 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 pre-existence 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). Decision makers typically manage risks holistically, while scientific information is generally derived using reductionist approaches (Meinke et al, 2006). The net outcome can be a ‘disconnect’ between scientists and decision makers with the result that climate and hydro-meteorological information can be developed that, although scientifically sound, may lack relevance (Cash and Buizer, 2005; Meinke et al, 2006; Vogel and O’Brien, 2006; Averyst, 2010). Perceptions of irrelevance, inconsistency, confusion, or doubt can delay action (National Research Council, 2009). Some studies (Lowe, 2002; Meinke, 2006; Glantz, 2005; Feldman and Ingram, 2009) advise scientists and practitioners to work together to produce trustworthy knowledge that combines scientific excellence with social relevance. These studies suggest that decision support activities should be driven by users’ needs, not by scientific research priorities, and that these user needs are not always known in advance, but should be identified collaboratively and iteratively in ongoing two-way communication between knowledge producers and decision makers (National Research Council 2009; Cash and Buizer, 2005). It has been suggested that this ongoing interaction, two-way communication, and collaboration allows scientists and decision makers to get to know each other, to develop an understanding of what decision makers need to know and what science can provide, to build trust and, over time, develop highly productive relationships as the basis for effective decision support (National Research Council, 2009; Feldman and Ingram, 2009; Averyst, 2010).

Since early warning information systems are multi-jurisdictional and multi-disciplinary, they usually require anticipatory coordination across a spectrum of technical and non-technical actors. National governments can play an important role in setting the high-level policies and supporting frameworks involving multiple organizations, in adopting multi-hazard and multi-stakeholder approaches and in promoting community based early warning systems (UNISDR, 2006b, Pulwarty et al, 2004). National governments can also 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 (UNISDR, 2006b). At the same time, national governments can also play an important role in supporting regions and sub-national governments in developing operational and response capabilities (UNISDR, 2006b; see 6.3.3.4).

6.3.3.2. Reducing Climate-Related Disaster Risk

National climate 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, following extreme climate impact events, humanitarian focused actions. Each of these strategies can prove ineffective in isolation but effective in combination. 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*

Climate change has the potential to negatively 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 (Wilby, 2007; Auld, 2008a; Stevens, 2009). With potential increases in extreme events regionally, small increases in climate extremes above regional thresholds have the potential to result in large increases in damages to all forms of existing infrastructure nationally and to increase disaster risks (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 national governments and the majority of development and disaster specialists (Moser and Satterthwaite, 2008; Rossetto, 2007). Low- and middle-income countries, which report close to three-quarters of the world's urban populations, are at greatest risk from extreme events and also have a far greater deficit in adaptive capacity than do high-income countries largely due to backlogs in protective infrastructure and services and limitations in urban government (Moser and Satterthwaite, 2008; Satterthwaite et al. 2007).

An inevitable result of potentially increased damages to infrastructure will be a dramatic increase in the national resources needed to restore infrastructure and assist the poor most affected by damaged infrastructure (Freeman and Warner, 2001). A study by the Australian Academy of Technological Sciences and Engineering (ATSE) concluded that national retrofit measures will be needed to safeguard existing infrastructure in Australia and new adaptation approaches and national codes and standards will be required for construction of new infrastructure (Stevens, 2008). Recommendations from this study call for: research to fill gaps on the future climate risks, 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 national adaptation options to deal with projected impacts to the built environment range from deferral of actions pending development of new information to modification of infrastructure components according to national guidance, 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).

The implementation of adequate national building codes that incorporate 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, assuming 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 typically designed using analysis of historical rainfall records (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 national climate change guidance, tools and consistent adaptation options be developed to ensure that climate change can be incorporated into infrastructure design (Stevens, 2008; Wilby et al, 2009; Auld, 2008b). While some 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 projections into engineering risk management and legislation, especially for elements such as extreme winds and extreme precipitation and its various phases (e.g. short and long duration rainfalls, freezing rain, snowpacks) (Wilby, 2010; Auld, 2008a; Sanders and. Phillipson, 2003; Lu, 2009). A few successful cases are emerging. In one example, the Canadian Standards Association (CSA) and its National Permafrost Working Group developed a Technical Guide, CSA Plus 4011-10, on "Infrastructure in Permafrost: A Guideline for Climate Change Adaptation" that directly incorporates climate change temperature projections from an ensemble of climate change models. This Guide factors in climate change projections of temperature and precipitation and risks from melting permafrost to foundations over the planned lifespans of the structure. The guide also suggested possible adaptation options, taking into account the varying levels of risks and the consequences of failure for foundations of structures, whether buildings, water treatment plants, utilidors, towers, tank farms, tailings ponds or other infrastructure (NRTEE, 2009; Canadian Standards Association, 2010; see Chapter 9 case study 9.x.x on vulnerable regions: The Arctic).

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 national building standards or inadequately account for local climate conditions (Rossetto, 2007). While the perception in some developing countries is that national 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). 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 national efforts for their up-take and implementation (Rossetto, 2007). Bangladesh, for example, 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). 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).

National support for land and water use planning that protects and enhances “green infrastructure” or natural buffers and defences can significantly reduce vulnerabilities for the built environment under current and future climate change. These ecosystem based adaptation approaches are discussed in section 6.3.3.2.3.

6.3.3.2.2. Promoting human development and secure livelihoods and reducing vulnerability

Vulnerabilities to climate related hazards and the options to reduce them vary between and within countries due to factors such as poverty, social positioning, geographic location, gender, age, class, ethnicity, ecosystem condition, community structure, community decision-making processes and political issues (Yodmani, 2001; UNISDR, 2009c). 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 issues of these most vulnerable countries (see section 7.4.3 for more details). Within these countries, the most vulnerable are usually those who are least able to cope with climate hazards due to a paucity of skill-sets, resources and access to assets for adaptive capacity. Studies indicate that national policies can increase this capacity (Davies et al, 2009; Heltberg et al., 2009; UNISDR, 2009c).

The most vulnerable communities may require full scale assistance to protect lives, properties and livelihoods (UNISDR, 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). Climate change may 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 one of the key adaptation actions 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 been limited (Ayers and Huq, 2009). Nonetheless, some developing countries have implemented successful policies and plans. Nationally, good progress is being made in strengthening some disaster reduction capacities for disaster preparedness and early warning and response systems and in addressing some of the underlying risk drivers in many developing country regions and sectors (UNISDR, 2009c; also see Chapter 9 case study 9.x.x). 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 (UNISDR 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, 2009c).

Many of the most vulnerable people who live below the International poverty line live and work in rural areas and are greatly impacted by disaster impacts (UNISDR, 2009c). Poor rural areas as well as many of the poor urban centers are often characterized by vulnerable housing, weak emergency services and infrastructure and a dependence on agriculture and other natural resources (UNISDR, 2009c; Reid et al, 2010). A high sensitivity to weather and climate variability combined with a lack of access to the necessary productive inputs for improved crop yields (e.g. productive land, seeds, fertilizer, irrigation, financial assets) means that rural poor in particular have low resilience to even the smallest weather irregularity (UNISDR, 2009c; IRI, 2006).

In reality, when faced with food scarcity, these poor populations often adopt maladaptive coping strategies that aggravate long-term disaster risks, such as overgrazing, deforestation, unsustainable extraction of water resources (UNISDR, 2009c; IRI, 2006). Short-term but limited strategies to minimize these risks include diversifying livelihoods to spread risk, farming in different ecological niches and building social networks to pool risks (UNISDR, 2009c). In the longer-term, climate change is expected to lead to more erratic food productivity and to even lower levels of output, requiring changes towards higher agricultural productivity, reduced production variability and agricultural systems that are more resilient to disruptive events (IPCC, 2007b; Stern et al, 2006; Cline, 2007; FAO, 2010; UNISDR, 2009c). This will require transformations in the management of natural resources and new climate-smart-agriculture policies, practices, tools and financing for food security, as outlined by the FAO (2010). FAO (2010) also developed carbon balance tools to assess greenhouse gas reduction impacts for these newly proposed food security and agriculture policies and practices, and these tools now being used in many countries. Other coping strategies include increased non-farm incomes, migration, government and other financial assistance, microfinance, social protection and index-based crop insurance (UNISDR, 2009c). The Sustainable Livelihoods Approach or Framework has been used internationally for rural and coastal development to holistically describe the variables that impact livelihoods locally and to define the capacity, assets (both natural and social) and policies required for sustainable living, poverty reduction and recovery from shocks (Allison and Horemans, 2005; Bennett, 2010). Chapters 2, 5 and 9 also discuss sustainable livelihood approaches that can be considered in building adaptive capacity and resilience to climate shocks in communities.

A crucial aspect in reducing vulnerability of climate-related risks among the most vulnerable - including food insecurity - is to make climate-related and climate change information available and accessible to decision-makers (IRI, 2006; Wilby et al., 2009; Washington et al., 2006), as discussed in section 6.3.3.1.1. developing countries in Africa, and particularly in the Sub-Saharan African economies, are especially susceptible to climate variability and change due to their predominately agrarian structure (IRI, 2006). Since food security crises in these countries are associated with climatic extremes, Sub-Saharan Africa currently represents the only region of the world where childhood malnutrition is actually increasing (IRI, 2006). There is growing recognition that better management of and responses to short and long-term climate risk in these countries will represent both a crucial step toward achieving the Millennium Development Goals and an opportunity to build some of the resilience for adaptation to the uncertainties of a changing future climate (IRI, 2006). Recent studies from Africa have shown that while climate information exists that could aid decision makers in making “no regret” adaptation decisions, this information is seldom incorporated into decisions (IRI, 2006; Ayers and Huq, 2009). In some cases, limited access to weather and climate forecasts in a timely manner also prevents the use of weather and climate information. The integration of climate information and services to support climate risk management of sensitive livelihoods will depend on effective use of communication infrastructure and networks to reach users, to facilitate climate awareness and education campaigns, and to receive feedback so that users can help shape the services they receive (IRI, 2006).

In many developing countries, one of the potential barriers for identifying the most vulnerable regions and people under future climate change is the limited human resource capacity to downscale global and regional climate projections to a scale suitable to support national level planning and programming process (Wilby et al., 2009; CCCD, 2009; Washington et al., 2006), and as discussed in section 3.2.3. Even when available, their use can be limited by a lack of understanding and interpretation on the degree to which these downscaled projections can highlight vulnerabilities.

National Adaptation Programme of Actions (NAPA) under the UNFCCC process have been able to assess the climate sensitive sectors and prioritize projects to address the most urgent adaptation issues of the most vulnerable regions, communities and populations in 49 least developed countries (UNCTAD, 2008). While the NAPA process has proven instrumental in increasing awareness of climate change and its potential impacts in LDCs, it can be limited by its tendency to focus on a project rather than a national programme approach to adaptation and risk reduction and by challenges in mainstreaming these plans into national developmental plans and strategies (CCCD, 2009; Satterthwaite et al, 2007). Concerns have been raised on means to fund NAPA activities and in some cases, potential donors may see the NAPA as little different from development plans, given that countries often fail to demonstrate incremental climate change benefits (UNFCCC, 2008; Satterhwaite et al, 2007). A key challenge is to ensure that NAPAs don't just become other policy documents, without translation into concrete support for adaptation (UNFCCC, 2008; Satterthwaite, 2007).

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 (UNISDRUNISDR, 2007, UNEP 2006, 2009 and Sudmeier-Rieux and Ash 2009), improved livelihoods, 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 or modified, 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; UNISDR, 2007, 2009; Colls et al., 2009; Sudmeier-Rieux and Ash 2009; Reid and Huq, 2005; Secretariat of the Convention on Biological Diversity, 2009; Lal 2010). Although the scientific evidence base relating to the role of ecosystem services in mitigating many disasters is nascent, investment in natural ecosystem management has long been used to reduce risks of disasters (see Box 6-4). Forests, for example, have been used in the Alps and elsewhere as effective mitigation measures against avalanches, rockfalls and landslides since the 1900s (Bebi, 2009; Dorren, 2004; Phillips and Marden, 2005; Sidle et al., 1985). The damage caused by wildfires, wind erosion, drought and desertification are 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), and depending on the width and age the mangrove stand can also contribute significantly to reducing damage from tsunamis (Yanagisawa et al. 2010).

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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 Indian Ocean tsunami in December 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)

_____ END BOX 6-4 HERE _____

Investment in natural ecosystems also contributes significantly to reduction in GHG emissions, through practices such as Land Use, Land Use Change and Forestry (LULUCF) and through Reduced Carbon Emissions from Deforestation and Forest Degradation (REDD) or REDD+ (which additionally includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks) (UNEP, 2006; Secretariat of the Convention on Biological Diversity, 2009).

REDD and REDD+ related strategies can help generate alternative sources of income for 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). Additional livelihood benefits are derived from the conservation and restoration of forest ecosystems and the services they support (International Union for the Conservation for Nature and Natural Resources and 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 and Singh et al. 2009). The extent to which ecosystems support such benefits though depends on a complex set of dynamic interactions 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, but unless specifically protected, sand dunes are frequently used as building material, or flattened to enhance views for seaside resorts. (Baird et al. 2005; Balmford et al, 2008; Björk et al. 2008; IOC, 2009; Kaplan et al., 2009; Yanagisawa, 2009; Yanagisawa et al., 2010). Scientific understanding of the relationship between ecosystem structure and function and the reduction of risks associated with climate extremes and disaster risks is limited, though growing.

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 Interventions Taking into Account the Role of Ecosystem Services

- 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 (UNISDR, 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).

______END BOX 6-5 HERE_______

Generally, ecosystem-based adaptation strategies, often referred to as 'soft' options, can be a more cost-effective adaptation strategy than hard infrastructures and engineering solutions, and produce multiple benefits. Many ecosystem-based options are often considerably more accessible to the rural poor (Sudmeier-Rieux and Ash2009). However, countries would need to overcome many challenges if they are to be successful in increasing investment in ecosystem-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 (OECD, 2009; Leslie and McLeod, 2007).
- Lack of capacity to undertake careful assessments of alternative strategies to inform choices at the local level. Such assessments could provide total economic value of the full range of disaster-related ecosystem services, compared with alternative uses of the forested land such as in agriculture (see, e.g., Balmford, 2002).
- Where they exist, data and monitoring on ecosystem status 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 (UNISDR, 2009a).
- The mismatch in geographic scales and mandates between the administration and responsibilities for disaster reduction, and that of ecosystem extent and functioning, such as in water basin (OECD, 2009; Leslie and McLeod, 2007).

6.3.3.3. Transferring and Sharing 'Residual' Risks

Risk sharing and transfer mechanisms for individuals and businesses at the local level are discussed in section 5.5.2.2. This section sets out the role of national institutions, especially governments, in enabling and regulating practices at the local and regional scales. It also discusses the need on the part of some governments to transfer their risks.

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. Some literature distinguishes between protection and promotion models, while acknowledging that in many instances hybrid combinations may contain elements of both (Hess and Hazell 2009). 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 (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, 1991). 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; Mahul and Ghesquiere, 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 (Mahul and Ghesquiere, 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).

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 want to consider creating enabling environments for the private sector to become more engaged or offer insurance themselves as well as ensure financial oversight and monitoring of implemented schemes (Warner et al., 2009).

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. For the development context, Hazell and Hess (2010) 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). As one example, 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, penetration is often much less than 100%. In some highly exposed countries, such as the Netherlands for flood risk, insurance is even non-existent and government relief is dispensed in lieu (Botzen, W. and van den Bergh, J., 2008). In many developing countries, there is little in terms of insurance for disaster risks, yet novel index-based microinsurance solutions have been developed and are starting to show results (Hazell et al., 2010; Hazell and Hess, 2010) (see also ch.5 and ch.9 case study on risk financing).

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 *et* al. 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. As discussed above (see secion 6.3.2.3), post-disaster sources of finance have often proven woefully inadequate to assure timely relief and reconstruction and pre-disaster risk financing arrangements may be worth considering. Yet, in wealthy countries, government insurance hardly exists at the national level and in Sweden, insurance for public assets is illegal (Linnerooth-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, 1991). 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 these conditions, however, applies to small, low-income and highly exposed countries (see section 6.3.2.3). 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 (Mahul and Ghesquiere , 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) (see Box 6-3 and ch.9 case study on risk financing). These transactions 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

Even in the rare circumstances where efforts outlined previously are all in place, there still needs to be investment in capacities to manage potential impacts as risk cannot be reduced to zero (Coppolla, 2007; Pelling, 2003; Wisner et al.2004). The scale of the disaster impact should ideally dictate the level and extent of response. Individual household capacities to respond to disasters may be quickly overwhelmed, requiring local resources to be mobilised (Del Ninno, 1998). When community-level responses are overwhelmed, regional or central government needs to be called upon (Copolla, 2007). Some events overwhelm national government capacities, and requires mobilisation of the international community of humanitarian responders (Fagen, 2008; Harvey, 2009). International responses pose the most complex management challenges for national governments, because of the diversity of actors that are involved and the multiple resources flows that are established (ALNAP, 2010a; Bennet, J, et al, 2006; Borton, 1993; Ramalingam, 2008). However, although humanitarian principles call for a proportionate and equitable response, in practice there are a few high-profile disasters that are over-resourced, with many more that are ‘forgotten or neglected emergencies’ (Slim, 2006; Walker et al. 2005). Despite the definition of international or national disasters as those where immediate capacities are overwhelmed, evaluations routinely find that most of the vital life-saving activities happen at the local level, led by households, communities and civil society (See Chapter 5, ALNAP, 2005; Hilhorst, 2003; Smillie, 2001, Telford and Cosgrave, 2006).

In terms of how responses are managed nationally, there are different models to consider (ALNAP, 2010b). Many countries now have some standing disaster management capacity (Interworks, 1998) and this should be considered distinct from national systems for managing disaster risk, commonly associated with ‘national platforms’ detailed in section 6.3.2. Examples of standing disaster management capacity include the Federal Emergency Management Agency in the US, Public Safety in Canada, National Disaster Management Authorities in India and Indonesia and the Civil Contingencies Secretariat in the UK. Comparative analysis of these structures shows that there are a number of common elements (Coppolla, 2007, Interworks, 1998). Countries with formal disaster management structures typically operate a system comprised of a National Disaster Committee, which works to provide high-level authority and ministerial coordination, alongside a National Disaster Management Office (NDMO) to lead the practical implementation of disaster preparedness and response (Interworks, 1998).

- National Committees are typically composed of representatives from different ministries and departments as well as the Red Cross/Red Crescent. They might also include donor agencies, NGOs and the private sector. The committee works to coordinate the inputs of different institutions to provide a comprehensive approach to disaster management.
- NDMOs usually act as the executive arm of the national committee. Focal points for disaster management, NDMOs are usually staffed by professional disaster managers NDMOs may be operational, or in large countries they may provide policy and strategic oversight to decentralised operational entities at federal or local levels.

Government ownership of the national disaster management function can vary with three models evident: It may reside with the presidential or prime ministerial offices, it may sit within a specific ministry, or it may be distributed across line ministries (Interworks, 1998). The way in which the international community is engaged in major emergencies is shaped by existing national capabilities and social contracts, with four possible response approaches (Chandran and Jones 2008; ALNAP, 2010b, see Table 6-4). Analysis based on these broad categories helps clarify the ways in which international agencies are mobilised to manage disaster impacts.

[INSERT TABLE 6-4 HERE:
Table 6-4: Typology of response.]

Details of the disaster management systems of two of the countries listed in Table 6-4 are outlined in Box 6-6.

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Box 6-6. National Disaster Management Systems of China and Kenya

China

The Government's disaster management process (called the 'disaster emergency response' in official documents) is a comprehensive system involving various central and local government sectors and covering the different phases of disasters preparedness, response and recover / rehabilitation. China has enacted more than 30 laws and regulations related to disaster management, including the Law on Earthquake Preparedness and Disaster Reduction. The national legislature adopted the Emergency Response Law on 30 August 2007 as the overall legal document governing all emergency responses in China, including disaster response.

Under the related law and regulations, the Government has established an emergency response system comprising three levels:

- The National Master Plan for Responding to Public Emergencies - an overall framework to be used at all levels of government to ensure public security and cope with public emergency events, including all disaster response activities.
- Five national thematic disaster response plans which outline the detailed assignment of duties and arrangements for major disaster response categories – natural disaster relief; flood and drought; earthquakes; geological disasters and very severe forest fires.
- Emergency response plans for 15 central Government departments and their detailed implementation plans and operation norms (UNESCAP, 2009).

Kenya

The government is working towards a national disaster management policy with the intention of preventing disasters and minimising the disruption they cause through taking steps to reduce risks. The policy will help enhance existing capacities by building resilience to hazard events, build institutional capacity, developing a well-managed disaster response system, reducing vulnerability and ensuring that disaster policy is integrated with development policy and poverty-reduction and takes a multi-sectoral, multi-level approach. The Ministry of State for Special Programmes will be responsible for the co-ordination of the disaster management policy and will promote integration and coordination of disaster management and will establish a national institute for disaster research to improve systematic monitoring and promotion of research.

The draft policy published in 2009 stressed the central role of climate change in any future sustainable planned and integrated National Strategy for Disaster Management. It sets out principles for effective disaster management, codes of conduct of different stakeholders, and provides for the establishment of an institutional framework that is legally recognized and embedded within the government structures. It stresses the importance of mobilising resources to enable the implementation of the policy, with provision of 2% of the annual public budget to a National Disaster Management Fund.

At the time of writing, this policy has not reached Parliament for discussion and approval (MOSSP, 2009, 2010).

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Although the level of response and actors involved can vary considerably between disasters and countries (ALNAP, 2010a), the basic actions taken to manage disaster impacts remain the broadly the same across countries, and correspond closely to the different stages of the disaster timeline (see Table 6-5; Copolla, 2007). In general, disaster management employs immediate activities, needs assessments and the delivery of goods and services to meet requirements. The demand for water, food, shelter, sanitation, healthcare, security and – later on - education, employment, reconstruction and so on is balanced against available resources (Wisner and Adams, 2003).

[INSERT TABLE 6-5 HERE:
Table 6-5: Disaster Management Actions across the Disaster Timeline (adapted from Coppola, 2007 and ALNAP 2010a).]

Literature from the humanitarian community indicates that climate-related disasters are widely seen as playing a major role in the increasing the overall human impact of disasters and trends in disaster events are commonly attributed to climate change, even in the absence of robust scientific evidence (IASC, 2009a, IFRC 2009). As such, climate change is often cited as a reason for increasing pressure on both national and international disaster management capacities (Oxfam, 2007, IASC, 2009a, IASC, 2009b, HFP, 2007). Consequently, climate change-related considerations are increasingly featuring in literature on disaster management (Barret et al., 2007; IASC, 2009a, McGray, 2007, Mitchell and Van Aalst, 2008; Venton and La Trobe, 2008), although challenges remain in how climate information can be used as a direct guide to decision-making (IASC, 2009a).

The challenges of climate change calls for institutional changes to disaster management approaches that are far from trivial (Salter 1998), with such challenges including more appropriate policies and legislation; decentralization of capacities and resources; greater budgetary allocation; improved capacity building at the local level; and the political will to bridge the divide between disaster risk reduction activities and disaster management (Sanderson, 2000; UNISDR, 2005). Recent analyses of the need for greater innovation in international humanitarian responses (Ramalingam et al, 2009) present these shifts as among the most significant and important reforms the international system must undergo.

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 (Mitchell and Ibrahim 2010). As climate change is altering the frequency and magnitude of some extreme events (see Chapter 3) and contributing to trends in exposure and vulnerability (see Chapter 4), the efficacy of national systems requires review and realignment with the new challenges (Mitchell and Ibrahim 2010, Polack 2010, UNISDR GAR 2009). Literature suggests that the effectiveness of national systems for managing disaster risk in a changing climate will be improved if they integrate assessments of changing climate extremes and disasters into current investments, strategies and activities; seek to strengthen the adaptive capacity of all actors and address the causes of vulnerability and poverty recognising climate change as one such cause (UNISDR GAR 2009, Schipper 2009, Mitchell and Ibrahim 2010). In practice, this might require new alliances and hybrid organisations across government and potentially between countries, different actors to join the national system, new cross-sector relationships, a reallocation of responsibilities and resources across scales and new practices (Polack 2010, Hedger *et al*. 2010). 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 could occur – in assessing the effectiveness of disaster risk management in a changing climate (6.4.1), managing uncertainty and adaptive management (6.4.2) and in tackling poverty, vulnerability and their structural causes (6.4.3).

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 few national level assessments focussing on economic efficiency of management responses (see World Bank, 1996; Benson 1998; Mechler (2004)). A recent report, taking an economic lense to DRR, goes as far as suggesting that governments should in many instances prioritize spending on early warning (such as for floods), critical infrastructure, such as water and electricity lifelines, as well as, within limits, *environmental buffers* such as mangroves, forests and wetlands (World Bank 2010).

Where 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 variants of a multi criteria approach have been conducted (see Van Ierland, 2005; Debels et al., 2007; de Bruin et al. (2009). Debels et al (2007) develop a multi-purpose index for a quick evaluation of adaptation practices in terms of proper design, implementation and post-implementation evaluation and apply it to cases in Latin America. 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 modelling 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 (also see Chapter 8).

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 (Thompson and Gaviria, 2004; Tompkins, 2005; see Box 6-7). 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 integrated 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).

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Box 6-7. Building Resilience for Disasters in the Cayman Islands

The Cayman Islands (Tompkins et al. 2008) illustrates how factors such as flexibility, learning and responsive governance are helpful in managing risks. The National Hurricane Committee (NHC) manages hurricane disaster risk reduction in the Cayman Islands and is responsible for preparedness, response and recovery. Compared to other countries, the Cayman Islands have been successful in managing disaster risk. For example, in 2004 Hurricane Ivan (which was similar in magnitude to Hurricane Katrina that hit New Orleans in 2005) only caused two fatalities in the island. Key aspects that are relevant to built disaster resilience are flexibility, learning and adaptive governance (Adger *et al* 2005; Berkes, 2007), all are present in the case study. The NHC is a learning-based organization. It learns from its successes, but more importantly from mistakes made. Each year the disaster managers actively assess the previous year's risk management successes and failures. Every year the National Hurricane Plan is revised to incorporate this learning and to ensure that good practices are institutionalised. Evidence of adaptive governance can be observed, for example, in the changing composition of the NHC, their structure, network arrangements, funding allocation, and responsibilities. Policy makers are encouraged to design and to implement new initiatives, to make adjustments, and take motivated actions. Creating such space for experimentation, innovation, learning, and institutional adjustment is crucial for disaster resilience.

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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, Eriksen *et al*, 2011). 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; 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 or external shocks (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, after the seminal paper published by Holling in 1973, 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 designed to fit different local contexts and to show the success, the potential losers from this policy may go unnoticed, causing problems with policy implementation and legitimacy (Eakin et al. 2009). Please see the 'glossary' for the report's definition of resilience.

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 (UNISDR 2009), 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 (UNISDR, 2009). Climate change adaptation and disaster risk reduction share similar interests in promoting measures to to reduce vulnerability – those which address inequity, promote secure livelihoods, act against discrimination, and increase access to power and resources, among others (Mitchell and Van Aalst 2008, Tanner and Mitchell 2008, Mitchell and Ibrahim 2010; Schipper 2009). However, strategies for tackling the risks of climate extremes and disasters, 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 (UNISDR 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 national social protection measures as discussed with reference to the local scale in chapter 5 (see table 5.4) and more broadly in Chapter 8. Other options include mainstreaming disaster risk management and climate change adaptation within poverty reduction strategies or strengthening local government and NGO capacity for community-based development in areas with concentrations of hard-to-reach, vulnerable populations (Tanner and Mitchell 2008; Mitchell and Van Aalst 2008).

6.4.4. 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 the trends in extreme events described in chapter 3, as well as by addressing the trends in exposure and the underlying drivers of vulnerability.

Strategies for mainstreaming climate change responses 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 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. Knowledge Gaps

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 sub-national 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).
- 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 (FAQs)

1) What constitutes a national system for managing risks and disasters associated with climate extremes?

A national system of disaster risk management ideally comprises of nation-wide multiple actors and stakeholders - national and sub-national government agencies, private sector, research bodies, international and regional non-government organizations, and community-based organizations and communities - working in partnership across all levels of society. These actors carry out differential but complementary roles according to their accepted functions and effectiveness and across spatial and temporal scales, to minimize exposure, reduce risks and vulnerabilities of communities and assets and assist communities to reduce their own exposures and risks, prepare them to respond quickly and efficiently to disaster events and residual risks and have capacity to rebuild and rehabilitate following disaster events.

2) What functions do key national systems' actors play in managing risks of climate related extreme events and disasters?

National and sub-national government agencies generally play multiple roles and functions in managing the risk of climate extremes and disasters. These vary between countries depending on the strength of the governments and their technical and budgetary capacity. The differential but complementary roles of national systems' actors can be categorized from a functions perspective into creating an enabling environment of policies, plans, legislation, organizational arrangements, coordination mechanisms; building knowledge and capacity to assess and identify risks and implement appropriate responses, including transferring and sharing risks through insurance and social safety nets; as well as generation and communication of information about hazards and risks, and appropriate responses.

These functions may include building and developing policy, regulatory and institutional frameworks that prioritize risk reduction; integrating disaster risk management with other policy domains, such as economic 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. Governments often also provide direct services for the management of disaster risks and climate extremes, including early warning systems, and measures to support the most vulnerable in society; research and public awareness related to disasters and training in subjects such as disaster preparedness and response. Certain aspects of disaster risk management in some countries may be suited to and delivered by non-government stakeholders, including the private sector, to implement; albeit this would most effectively be coordinated within a framework created by national and sub-national governments.

The private sector has traditionally played an important role in DRM, including risk financing and insurance, engineering and construction, information communication technology, media and communication. Under changing climatic environments the roles the private sector plays is changing including an enhance uptake of corporate social responsibility (CSR) in terms of advocacy and general awareness raising for DRR and involving humanitarian funding support and the contribution of volunteers and expertise; Public Private Partnerships (PPP) enhancing the provision of public goods for DRR in joint undertakings of public and private sector players; and businesses model approaches. Innovative risk sharing mechanism such as indexed catastrophic insurances and micro insurances for poverty alleviation and reducing risks through development efforts are also emerging private sector roles.

Civil Society and Community-based Organizations (CSO and CBOs) are part of national systems. Civil societies have provided humanitarian support and many other services including specific activities targeting education and advocacy, environmental management; sustainable agriculture; infrastructure construction, as well as increased livelihood. Their role in changing climate conditions is becoming even more critical as they largely operate on the ground with communities building their awareness and knowledge and capacity to understand their climatic risks, prepare for, respond to and rebuild after extreme events and disasters.

Bilateral and multilateral agencies are also major players in developing countries supplying financial and technical support to government and non-government agencies, as well as local communities and NGOs and CSOs, to tackle multifaceted challenges of disaster risk management. They vary in their approaches and modalities and support different aspects of risk management and climate change adaptation. Efforts in the past have generally focused on providing post disaster humanitarian and post disaster rehabilitation assistance, with almost 90% of their budget going towards disaster relief and reconstruction, and only less than 10% of the funds for preparedness and risk reduction. Recently the need for allocating resources also to disaster risk reduction assistance has been acknowledged, with increasing levels of resources, albeit still relatively small in comparison to budget allocation, identified for various disaster risk reduction efforts, including poverty reduction as a means of reducing risks and vulnerability.

Scientific and research organizations play important roles as well by undertaking research and assessments on subjects such as the evolution and consequences of past hazard events - cyclones, droughts, sandstorms and floods-; analyzing spatial and temporal patterns of weather-related risks; building cooperative networks for early warning systems, modeling, and long-term prediction; actively engaging in technical capacity building and training; transforming scientific evidence into adaptation practice; collating traditional knowledge and lessons learnt for wider dissemination, and translating scientific information into user-friendly forms for community consumption. The effectiveness of different actors and stakeholders in managing climate extremes and disasters risks is highly dependent on the policies, legislation and other enabling environments as well as the capacity of the stakeholders to proactively take steps. Also the availability and communication of robust and timely scientific information and traditional knowledge to all stakeholders and actors is key.

3) What can governments do to help reduce risk and manage residual risks of climate change related extremes and disasters?

Governments at all levels are well placed to provide the enabling environments in support of actors and stakeholders to cost effectively and equitably play their part in a multifaceted disaster risk management. National and sub-national governments can utilize a range of planning and policy options to create necessary enabling environments for government agencies, sub national and municipal governments, private sector and individuals to reduce exposure to hazards, reduce risks and manage residual risks of climate change related extremes and disasters. Planning and policy options range from targeting key underlying drivers and determinants of risks and vulnerability – such as poor human development status,; poor access to water and sanitation; unsustainable resource and environment use - to information generation and knowledge management; provision of private sector incentives to supply services such as insurance and microfinance; and coordination of post disaster response and rehabilitation efforts..

Governments can adopt longer term “no regrets” vulnerability options, which include some traditional disaster risk reduction (DRR) approaches to deal with the existing climate conditions and can be justified under all plausible future climate change scenarios, including no climate change. “No regret” actions would include interventions to enhance the provision and dissemination of climate information for agriculture in drought-prone regions, improvements to hazard warning and dissemination systems and updates to climatic design information for engineering codes and standards.

At the other end of the spectrum, some long-term, high implication planning issues involving large investments involve climate change impacts' studies and may also incorporate additional redundancies that account for the uncertainties of the future climate. Given the consequences, the potential irreversibility of decisions, significant investment costs and the long-lived nature of these national decisions, more climate information may be needed to treat the range of uncertainties for the future. In between these ranges lies a broad spectrum of activities with gradations of emphasis on vulnerability and impacts. In some cases, mal-adaptation can occur in the longer term when "no regret" actions for current climate vulnerabilities do not consider climate change impacts (e.g. changes to agricultural livelihoods to strengthen resilience today could undermine DRR gains over the longer term when climate change impacts on future flood risks are ignored).

Policies can also comprise of a range of financial instruments suitable under both current and future climate conditions. Key risk transfer options include insurance, micro-insurance and micro-financing, government disaster reserve funds and intergovernmental risk sharing. The latter two help to provide much needed relief, immediate liquidity after a disaster in regions where individual countries because of their size cannot have viable risk insurance schemes. They acan 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. The decision to bear residual losses is always in the background as due to financial and other constraints generally very low probability events cannot be fully adapted to and uncertainties over the directions of future climate change impacts can be high. Also, often, there are important constraints in terms of limited capacity or a small set of available adaptation options
.

When evaluating options, the scale of potential climate-related disaster risks, the capacity of governments or agencies to act, the level of certainty on future changes, the timeframes within which these future impacts and disasters will occur and finally the costs and consequences of decisions to be taken are key considerations in a government's prioritization and finally implementation. In terms of appropriate methods, cases with greater certainty in projecting future climate change impacts may better lend themselves for climate change impacts and modelling approaches while cases where a country's adaptive capacity is low or the uncertainties over future climate changes are high may be more suited to the "no regrets" and vulnerability-oriented approaches. All options are best implemented or mainstreamed through sectors and other policies and between sectors, including those for agriculture, water resources, infrastructure, health, land use, environment, early warning services, finance and planning, poverty reduction, educations, hydro meteorological science.

Given competing priorities and development goals, policy makers of national and sub-national governments may prefer to consider win-win outcomes that result in synergies for disaster risk reduction, climate change adaptation, greenhouse gas reduction and human development. An example involves ecosystem based adaptation, as healthy, natural or modified, ecosystems have a critical role to play in reducing risk of climate extremes and disasters. Although the scientific evidence base relating to the role of ecosystem services in mitigating many disasters is nascent, investment in natural ecosystem management has long been used to reduce risks of disasters. Sustainable land management, including reforestation and conservation of forests, reduces risk of landslides, avalanches, and floods. Wetland protection and other coastal ecosystem conservation serve to protect against coastal storm surges. Such ecosystem based adaption also contributes towards increased and sustainable economic opportunities, increased carbon sequestration and greenhouse gas mitigation in some cases. In many cases it can be more cost effectively replace or complement other adaptation actions like building expensive 'hard' infrastructure such as sea-walls and dykes. In an ecosystem based approach, in essence governments work towards streamlining their planning processes so that development, environmental management, disaster management and climate agendas are successfully combined.

4) How can countries integrate considerations of increasing risks of climate change related extremes and disasters to reduce risks, transfer and manage residual risks?

Countries can integrate or mainstream considerations of increasing risks of climate change related extremes and disasters into their plans, policies, strategies, programs, sectors and institutions in multiple ways and at all levels. A key challenge and opportunity in mainstreaming or implementing DRR and CCA actions lies in building bridges between current disaster risk management actions to deal with existing climate vulnerabilities and the additional and revised efforts needed for adaptation to future climate change. The ultimate challenge is the need for transformational change across the society where risk becomes a central component of social, economic and environmental development efforts, recognizing that it is the social processes which transform natural or technological phenomena into disasters and create and increase human vulnerability.

Several studies advocate a concurrent or twin-track approach to mainstreaming CCA and DRR, consisting of: (1) "bottom-up" approaches or vulnerability assessments of social and economic strategies for coping with present climate extremes and variability, as practiced by the DRR community and (2) "top-down" approaches using climate forecast tools and scenarios to evaluate sector-specific, incremental changes in risk over the next few decades. The combination of 'top-down' and 'bottom-up' options allows vulnerability and impacts approaches to be "mixed and matched" for the realities of different geographic scales, uncertainties and governance mechanisms
.

In many cases, these approaches can be combined by considering a range of climate change scenarios and impacts relative to critical vulnerability thresholds defined by decision-makers. In other cases, changing climate risks can be monitored and mainstreamed into decision-making through regularly updated revisions to hazard and vulnerability assessments. Redundancies can be incorporated into existing disaster management planning in order to strengthen against the unforeseen risks of the changing climate. When available, downscaled ensembles of future climate change and socio-economic scenarios, impact models, vulnerability assessments and their uncertainties can be incorporated or mainstreamed into national and sectoral plans.

Mainstreaming nationally across multiple sectors requires governance mechanisms and coordination that can cut across national and subnational government agencies and sectoral organizations and may best be realized if all areas of government are coordinated from the highest political and organizational level.

Mainstreaming DRR and CCA also requires good and relevant information being available to actors and stakeholders in the form that could be understood and acted upon. Good information includes not only scientific information about hazards and trends but also about the underlying ecological, social and economic drivers and determinants of risks and vulnerability, and appropriate responses. For example, increasing biological diversity of ecosystems allows a greater range of ecosystem responses to hazards, and this increases the resilience of the entire system. Research has shown that reducing non-climate stresses on ecosystems, such as coral reefs and rainforests can enhance their resilience to climate change. Moreover, intervention on the socio economical factors that trigger disasters implies reducing vulnerability that have to do with: low income, inappropriate technology, absence of land use planning, inappropriate education, lack of organization, institutional weakness and political willingness. Comprehensive considerations of the multifaceted determinants of increasing risks of climate change related extremes and disasters and responses required to reduce risks, transfer and manage residual risks suggest a need for relevant and appropriately sequenced multidisciplinary and experiential knowledge sets – natural hazard identification and patterns, risk construction processes, and evaluation and assessment.

Recent successful experiences suggest that the production and communication of relevant scientific and other knowledge to decision-makers and actors can be best be achieved by a co-generation of knowledge through scientists and researchers in collaboration with policy makers and other non-academic stakeholders. Collaboration between scientific disciplines, adopting transdisciplinary methodologies also helps generate a body of complementary and appropriately sequenced knowledge that generates synergistic outcomes.

5) What methods and tools are currently available to help develop a culture of resilience by assessing risks, reducing climate-related disaster risks through hard and soft options and transferring and sharing 'residual risks?

Information and knowledge is crucial for the development of different methods and tools that may help to reduce risks, improve the planning processes, help in the recovery process and improve the capabilities to adapt to a changing climate. Building a culture of resilience involves not only natural hazard identification and an understanding of the root causes of exposure, vulnerability and risk, but also the communication of knowledge to actors and decision-makers, designing residual risk preparedness procedures for effectively responding to disasters when they occur and finally an evaluation and assessment of adaptive learning.

Some examples of assessment methods, and tools are: climate change modeling, hazard zoning,"hot spot" mapping", national vulernability mapping and monitoring using vulnerability indices, easonal outlooks for preparedness planning. DRR options include early warning systems for fluvial, glacial, flood and tidal hazards; structural and non-structural flood controls, artificial draining of pro-glacial lakes, traditional rain and groundwater harvesting, and storage systems, long-range reservoir inflow forecasts and water demand management and efficiency measures.

National climate-related disaster risk reduction activities include a broad range of national options that vary from "hard" structural options for safer and future oriented national infrastructure and building codes, coastal defense practices, standards for maintenance of enhanced early warning systems to "soft" options that include policies for more rigorous land use planning, protection of natural ecosystems, human development, and financial instruments for promoting human development and disaster risk sharing and risk transfer (see Table 6-6).

[INSERT TABLE 6-6 HERE:
Table 6-6: Some examples of methods/tools/practices for assessing risks, reducing climate-related disaster risks, and transferring and sharing risks.]

"Hard" structural or engineering options include new and revised construction practices, implementation of adequate national building codes that incorporate regionally specific climate data and analyses to improve resilience for many types of risks. Since infrastructure is built for long life-spans and the assumption of climate stationarity will not hold for future climates, it is important that national climate change guidance, tools and consistent adaptation options be developed to ensure that climate change can be incorporated into these national infrastructure design standards. Meanwhile, challenges remain on how to incorporate the uncertainty of future climate projections into engineering risk management and legislation, especially for elements such as extreme winds and extreme precipitation. Examples are emerging where these challenges have been overcome successfully at the national level, for example, climate change related uncertainties are now incorporated into the national permafrost standard for Arctic regions of Canada and the design of cyclone-resistant temporary houses in Bangladesh.

Soft options for resilient infrastructure and communities include ecosystem-based adaptation strategies, which can prove to be more cost-effective adaptation strategies than hard engineering solutions alone and produce multiple benefits. Many ecosystem-based options are also more accessible to the rural poor and can support livelihoods. Land use planning and management that aims to protect and enhance functioning "green infrastructure" or natural buffers and defences such as wetlands, forests and natural drainage corridors can reduce vulnerabilities in the longer term. Index-based catastrophe insurance often linked to microfinance and microinsurance are some recent tools that have also proven successful in DRR. Hard structural options alone, without the support of soft ecosystem based services, private sector engagement and incentive based financing of DRR, may first prove to be very expensive in terms of construction and maintenance and then may not bring abut the expected benefits as they can lead to over-reliance on structures, which may fail catastrophically in large events.

For building resilience and reducing risk, information and knowledge needs to be translated into concrete actions, measures and tools to deal with disaster risk and climate change adaptation. Effective communication and public awareness for action is critical when trying to reduce risks and disaster losses and damages. Early Warning Systems are essential tools to promote both risk assessment and public awareness in order to promote a culture of resilience as they can deliver accurate, timely, and meaningful information. To be effective and complete, an early warning system should comprise of four interacting elements (i) generation of risk knowledge including monitoring 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 and how it promotes changes in planning and future policies.

6) How can governments facilitate increased engagement of the private sector in managing risks associated with climatic extremes and climatic variabilities?

The private sector has always been involved in disaster risk management particularly providing services such as post disaster engineering and construction, information communication technology, media and communication, utilities and transportation. But little evidence has been documented in relation to successful national systems level private sector engagement, with the exception of risk financing. There is scope for increased private sector involvement in DRR by creating increased awareness and understanding and highlighting a business case for private sector engagement, such as for guaranteeing global value chains in the face of disasters. There exists scope for innovative private-public sector risk financing partnerships in the supply of innovative risk financing instruments, although private insurers are often not prepared to fully underwrite disaster risks. In response to this reluctance, countries could, as many OECD countries including Japan, France, the US, Norway and New Zealand have done, legislate public-private national insurance systems for natural disasters with mandatory or voluntary participation of the insured. Within such partnerships, in a development context governments could follow a promotion model of pro-poor regulation to increase market penetration of non-traditional risk financing measures, such as through micro-insurance schemes. In India, for example, the government passed a regulation where insurers were made to reserve a certain quota of business for low income insurance policies within their regular business segment. This government legislation effectively led to the cross-subsidization of the micro-insurance industry and has helped the poor in rural communities access insurance against disasters.

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Table 6-1: National policies, plans, and programs: selection of disaster risk management and adaptation options.

Sector/ Response	**Manage residual risks**	**Transfer of risks**	**"No regrets" or climate proof actions**	**Preparing for climate change by reducing uncertainties** ***('No regrets' options plus…)***	**Reduce future climate change risks** ***("Reducing uncertainties" options plus...)***	**'Win-win' for GHG reduction, adaptation, risk reduction and development benefits**
Natural Ecosystems and Forestry	▪ 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]	▪ 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]	▪ 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]	▪ 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	▪ Changed livelihoods and relocations in regions with climate sensitive practices [12]	▪ Improved access to crop, livestock and income loss insurance, (e.g. weather	▪ Food security via sustainable land and water management, training; Efficient water use, storage; Agro-forestry; Protection shelters,	▪ Increased agriculture-climate research and development [10] ▪ Research on climate tolerant crops, livestock; Agrobiodiversity for	▪ Adaptive agricultural practices for new climates, extremes [12] ▪ New and enhanced agricultural weather, climate prediction services [11]	▪ Energy efficient and carbon sequestering practices; Training; Reduced use of chemical

	▪ Emergency stock and improved distribution of food and water [12]	derivatives) [13] ▪ Micro-funding and micro-insurance [13] ▪ Subsidies, tax credits [13]	crop and livestock diversification; Improved supply of climate stress tolerant seeds; Integrated pest, disease management [8] ▪ Climate monitoring; Improved weather predictions; Disaster management, crop yield and distribution models and predictions [9]	genetics [10] ▪ Integration of climate change scenarios into national agronomic assessments [11] ▪ Diversification of rural economies for sensitive agricultural practices [10]	▪ Food emergency planning; Distribution and infrastructure networks [12] ▪ Diversify rural economies [12]	fertilizers [14] ▪ Promote Bio-gas from agri-waste and animal excreta[14] ▪ Agroforestry [14]
Coastal Zone and Fisheries	▪ Enhance emergency preparedness measures for changed extremes, including evacuations [16] ▪ Relocations of communities, infrastructure [16] ▪ Exit fishing; alternate livelihoods [19]	▪ Enhance insurance for coastal regions and resources; Fisheries insurance [21] ▪ Government reserve funds [21]	▪ 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]	▪ 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	▪ National preparedness and evacuation plans [24] ▪ Enhanced health infrastructure [24] ▪ Transport, engineering; temporary consumable water taking permits [24] ▪ Food , water distribution, alternate livelihoods [24]	▪ Public-private partnerships; Economics for water allocations beyond basic needs [26] ▪ Mobilize financial resources and capacity for technology and EbA [26] ▪ Insurance for infrastructur e	▪ 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 for resilient water infrastructure and water resource management; Improved institutional arrangements, negotiations for water allocations [23]	▪ 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 water resource management (e.g. catchments and river basins); joint river basin management (e.g. bi-national) [23]	▪ 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 quality forecasts for new conditions [24]	▪ Integrated water efficiency and renewable hydro power for CCA [23]
Infra-structure, Housing, Cities, Transport-ation, energy	▪ Relocation [28] ▪ Evacuation planning; Contingency plan for transport during extreme events [28] ▪ Climate	▪ Infrastructure insurance and financial risk management [29] ▪ Insurance for energy facilities, interruption [29]	▪ Building codes, standards with updated climatic values; Climate resilient infrastructure (and energy) designs; Training, capacity, inspection,	▪ Improved downscaling of CC information; Maintain climate data networks, update climatic design information; Increased safety/uncertainty factors in codes and standards; Develop	▪ Codes, standards for changed extremes; [30] ▪ Publicly funded infrastructure and post-disaster reconstruction to include CCA [30] ▪ New materials, engineering approaches; Flexible	▪ Implement energy and water efficient GHG reductions, DRR and adaptation synergies [29] ▪ Scale up, market penetration for renewable energy

	resilient shelter construction [28] ▪ Promote energy security; Distributed energy generation and distribution [29]	▪ Innovative risk sharing instruments [29] ▪ Government reserve funds [29]	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]	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]	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]	production; Increased hydroelectric potential; Sustainable biomass; "Greener" distributed community energy systems [29]
Health	▪ National plan for heat and extremes	▪ Extend and expand health insurance	▪ Community/urban planning, building standards and	▪ Research on climate-health linkages and CCA options; Develop	▪ New food and water security, distribution systems; air quality	▪ Promote use of clean renewable energy and water

	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]	coverage to include new and changed weather and climate risks [33] ▪ Government reserve funds [33] ▪	guidelines; cooling shelters; 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]	sources; increase energy efficiency; Air quality regulations; Clean energy technologies to reduce harmful air emissions (e.g. cooking stoves) [34]

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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 Polackova 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
A system of risk indicators: reflecting macro and financial health of nation, social and environmental risks, human vulnerability conditions; and strength of governance (Cardona et al. 2010)	Macroeconomic and financial impacts (DDI) Measures of social and environmental risks (LDI) Measures of vulnerability conditions reflected in exposure in disaster-prone areas, socioeconomic fragility and a lack of social resilience in general. Measures of organisational, development and institutional strengths (RMI)
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: Typology of response.

States where there is an existing or emerging social contract with its citizens, by which the state undertakes to assist and protect them in the face of disasters, and there is a limited role for international agencies, focusing on advocacy and fundraising	• China post-Sichuan earthquake • Chile post-2010 earthquake • USA post-Hurricane Katrina • Australia during 2010 floods
States that have a growing capacity to respond and request international agencies to supplement their effort in specific locally owned ways, through filling gaps in national capacities or resources	• Indonesia post-Earthquake • India post-Bihar floods • Mozambique post-2008 floods
States that have limited capacity and resources to meet their responsibilities to assist and protect their citizens in the face of disasters, and which request international assistance to cope with the magnitude of a disaster, resulting in a fully-fledged international response	• Haiti post-2010 earthquake • Bangladesh post Cyclone Sidr • Uganda post-2009 floods • Kenya 2009 drought
States that lack the will to negotiate a resilient social contract, including assisting and protecting their citizens in times of disaster. These pose significant challenges, and pose the greatest challenge; and involve a combination of direct delivery and advocacy	• Myanmar post-Cyclone Nargis • DRC post-Goma volcano • Zimbabwe

Table 6-5: Disaster management actions across the disaster timeline.

	Pre-disaster	Immediate post-disaster	Recovery
Disaster Management Actions	• Warning and evacuation • Pre-positioning of • resources and supplies • Last minute mitigation and preparedness measures	• Search and rescue • Emergency medical treatment • Damage and Needs Assessment • Provision of services – water, food, health, shelter, sanitation, social services, security • Resumption of critical infrastructure • Coordination of response • Donation management	• Transitional shelter in form of temporary housing or long-term shelter • Demolition of critically damaged structures • Repair of less seriously damaged structures • Clearance, removal and disposal of debris • Rehabilitation of infrastructure • New construction • Social rehabilitation • 'Building back better' to reduce future risk • Employment schemes • Reimbursement for losses • Reassessment of risks

Adapted from Coppola, 2007 and ALNAP 2010a

Table 6-6: Some examples of methods/ tools/ practices for assessing risks, reducing climate-related disaster risks and transferring and sharing risks.

Methods/Tools/Practices	Examples
Mainstreaming climate change considerations in development and disaster risk management	• Adaptation across project/community; ii) sector regulation and compliance; and or iii) policy and planning level (short- and mid-term policy making and planning at sub-national level and national strategic development planning in Cook Islands and Federated States of Micronesia {ADB, 2005 #2669}. • Swiss Development Cooperation's four year project in Muminabad, Tajikistan adopted an integrated approach to risk through reforestation and integrated watershed management (SDC, 2008). (see also chapter 8)
"Hard Options"	
Structural and non-structural flood controls	• Early warning and flood control systems for Mozambique (chapter-9)
Artificial draining of pro-glacial lakes	• The Tsho Rolpa glacial lake project in Nepal (Sperling and Szekely, 2005 (chapter-9)
Protection of natural ecosystems	• Forests, used in the Alps as effective mitigation measures against avalanches, rockfalls and landslides since the 1900s(Bebi, 2009; Dorren, 2004; Phillips and Marden, 2005; Sidle et al., 1985
Building code	• Permafrost standard for Arctic regions of Canada • Simple modifications to improve the cyclone-resistance of (non-masonry) kutcha or temporary houses in Bangladesh (Lewis and Chisholm, 1996; Rossetto, 2007
Coastal defence practices	• Artificial breakwaters in Maldives (Secretariat of the Convention on Biological Diversity, 2009)
Traditional rain and groundwater harvesting	• Marshall Islands, Bangladesh, Japan
"Soft Options"	
Ecosystem based adaptation	• Planting Mangroves in Viet Nam for coastal protection (Reid and Huq, 2005) • Application of holistic River Basin Management Plans and Integrated Coastal Zone Management (EC, 2009; DEFRA, 2005;Wood et al. 2008). • Brazil, 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).
Risk sharing and transfer	• Index-based reinsurance in Ethiopia for protection for its drought exposure under the World Food Program (chapter-9) • Supporting Index-based microinsurance in Bolivia • Insuring public relief expenditure in Mexico and the Caribbean region (Cardenas et al, 2007; Ghesquiere, et al 2006
Information and Communication	
Early warning and communication	• Cyclone warning system in Bangladesh (Paul 2009) • Early warning systems based on medium-range and seasonal forecasts across Europe and West Africa (Bartholmes et al. 2008; Tall et al. 2010)
Disaster Deficit Index (DDI) using integrated science, economics, social processes and traditional knowledge and expert knowledge	• Monitoring disaster risk and vulnerability in 19 Latin American countries (Cardona, et al 2010)

Chapter 7. Managing the Risks: International Level and Integration Across Scales

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Contents

Executive Summary

There are many organizations working at the international level to manage climate change and disaster risks. An assessment of the activities of all these organizations and how they work together is beyond the scope of this chapter. The focus of this chapter concentrates on the two main institutional arrangements for risk management at the intergovernmental level; that is the International Strategy for Disaster Reduction (ISDR) with its Hyogo Framework for Action (HFA), and the United Nations Framework Convention on Climate Change (UNFCCC). These are two quite different types of institutions; ISDR is an inter-agency strategy with a secretariat while the other is an international treaty.. Both are assessed in terms of their role in the international regimes for DRR and CCA respectively, and in the context of international development, especially as manifested in the Millennium Development Goals. Brief descriptions of the contributions of some selected other programmes and institutions are provided.

Although the mandate of this chapter and of the Special Report as a whole is to answer the question of how CCA might benefit from the experience of DRR it is clear from the literature reviewed that both might benefit from each other in a mutually supportive and synergistic way. From the perspective of many in the DRR management community, CCA should be factored into all disaster risk management. From the perspective of many in the CCA management community, weather-related disasters are or should be an important part of the adaptation agenda. Both these perspectives can be encompassed in a view that argues for closer integration at the international level between DRR and CCA, and that both should be brought more into the mainstream of international development and development assistance. There is a widespread recognition (especially in inter-governmental reports) that neither DRR nor CCA are well enough integrated into current development policies and practices (7.1.1).

Much of the literature tends to view disasters as localized and short-term events. Disaster risk management is often seen as a bottom-up process which begins at a disaster site with events on the ground and hence a matter first of local concern, then national and only international as a last resort, especially in terms of humanitarian assistance and emergency response. By contrast climate change has emerged as a top-down issue identified by science rather than by events, and in terms of first an international concern with the global common property of the atmosphere, being subject to long-term anthropogenic forcing.

These conceptions and perceptions are now changing more or less rapidly. Disasters are increasingly coming to be recognized as having spatially widespread causes and consequences. Global development patterns can help to increase vulnerability and create disasters. Large disasters themselves can have extra-territorial, regional and sometimes global consequences (systemic risks), linked to global security (7.2.1). As adaptation has gained in prominence in the climate negotiations the agenda has become increasingly concerned with adaptation at the local level, as well as with the broader strategic and developmental aspects of adaptation policy and strategy.

Both DRR and CCA involve questions of economic efficiency (7.2.2); solidarity (7.2.3) and subsidiarity (7.2.4); and changing international legal obligations and responsibilities (7.2.5). These elements of the rationale for international management action are assessed early in the Chapter, (7.2) and together with an analysis of existing inter-governmental institutions (focussing on ISDR and UNFCCC in 7.3) provide the basis for the conclusion that both DRR and CCA would be more effective if their institutional management were more closely integrated together and with sustainable development.

There are current strengths and weaknesses in the management of DRR and CCA and five major dimensions are selected for examination of constraints and opportunities at the international level. These are: international law, financing, technology transfer and cooperation, risk sharing and transfer, and knowledge creation, management and dissemination (7.4).

International law evolves slowly and is less advanced in DRR and CCA than in other related fields such as international humanitarian law. Broadening the scope of humanitarian law has been proposed, (and opposed) as an alternative to the further development of international law for DRR and CCA. The emerging legal doctrine of "responsibility to protect" has been proposed in application to natural disasters, and this has some similarity to the UN formulation of "common but differentiated responsibilities" in the Climate Convention (7.4.1).

Under the UNFCCC there is an obligation on developed country parties to assist the most vulnerable countries in meeting costs of adaptation. Several funds have been created under the Global Environment Facility and the Convention and more are in prospect. There is an expectation that a considerably larger fund (the Green Climate Fund) will be created and that within a decade tens of billions of dollars will be made available to support adaptation. There is no such fund available or in prospect for DRR, although CCA funds can, if closely integrated with DRR and development help to reduce vulnerability to disaster risks as well as climate change. Steps in this direction would be in conformity with the Paris Declaration for Aid Effectiveness including principle (c) which specifies "harmonization through simplified and common procedures and shared analysis". As another source of support for DRR it has been proposed that a portion of the internationally donated humanitarian disaster relief funds might be allocated to longer-term disaster prevention, which would also bring DRR into closer alignment with CCA (7.4.2).

There has been much attention to technology transfer and cooperation under the UNFCCC, although until recently this has focussed more on the reduction of GHG emissions than adaptation. There is also considerable attention to technology for disaster risk management, especially to advance and strengthen forecasting and warning systems and emergency response. These activities that are promoted through the HFA are widely dispersed among many international and national-level organizations and not closely linked to ISDR (7.4.3 and 7.4.5).

International risk sharing and transfer is a relatively new and expanding area of cooperation involving both CCA and DRR. Remittances; post-disaster credit; and insurance and reinsurance all have an established role in disaster response. Partly as a result of the concerns about climate change some alternative insurance instruments are in various stages of development and expansion including international risk pools, and micro-insurance. These processes and products are being developed by international financial institutions largely outside the purview of ISDR and the UNFCCC (7.4.4).

There is a substantial growth in research (knowledge generation) and its dissemination in relation to CCA encouraged and facilitated by the UNFCCC and also taking place spontaneously in many research institutions and programmes. Undoubtedly some of this is of benefit to DRR. New mechanisms of knowledge sharing, higher education and training using new technologies such as ICT are also being established at a rapid rate but these need to be coordinated to bring strong linkages between DRR, CCA and development issues (7.4.5).

The agenda for future policy development and research on DRR and CCA is very large, and is being addressed on many fronts both within and beyond the ISDR and the UNFCCC. The prospect of considerably expanded support for CCA is helping to promote a movement towards the closer integration of CCA with DRR and the mainstreaming of both into sustainable international development (7.5). Stronger financial support will facilitate progress in knowledge generation and dissemination; international risk sharing and transfer and technology development and transfer.

While there are grounds for cautious optimism one lesson from DRR to CCA is that stronger efforts at the international level do not necessarily translate to net progress on the ground. Much depends on how international efforts are integrated with the national and local levels. The considerable expansion of DRR through the International Decade for Natural Disaster Reduction (1991-2000) and the establishment of the ISDR have had mixed results – achieving some reduction in mortality and morbidity, and having much less success in the area of economic losses. The problems of disaster risk have continued to grow due to the relentless expansion in exposure and vulnerability even as the international management capacity has expanded. It is a race against time.

7.1. The International Level of Risk Management

7.1.1. Context and Background

A need to cope with the risks associated with atmospheric processes (floods, droughts, cyclones and so forth) has always been a fact of human life (Lamb, 1995). In more recent decades extreme weather events have increasingly come to be associated with large scale disasters, and an increasing level of economic losses. (Refer to Chapters 2 and 4.) Considerable experience has accumulated at the international (as well as local and national) level on ways of coping with or managing the risks.

The same cannot be said for the risks associated with anthropogenic climate change. These are new risks identified as theoretical possibilities or probabilities (IPCC 1990, 1995, first and second assessment reports) and subsequently confirmed as "unequivocal" (IPCC 2007 4th assessment report).

Acceptance of climate change and its growing impacts has led to a stronger emphasis on the need for adaptation, as exemplified, for example, in the Bali Action Plan (adapted at the 13th Session of the Conference of the Parties to the UNFCCC (UNFCCC, 2007).

The international community is thus faced with a contrast between a long record of managing disasters and the risks of "normal" climate extremes, and the new problem of adaptation to climate change and its associated changes in variability and extremes. A frequently posed question therefore asks how the comparatively new field of climate change adaptation can benefit from the longer experience in disaster risk management. It is also a major focus of this Special Report.

Although climate extremes have a negative effect they have helped to raise consciousness of climate change within the public and policymakers. This can then help to generate a further sense of 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 and La 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; UNDP, 2007).

The long term potential to reducing exposure to climate risks lies in sustainable development (O'Brien et al, 2008). Although each extends beyond the scope of the other both seek to build resilience through sustainable development (O'Brien et al., 2008).

This recognizes the need for disaster risk management to be a key component in the ongoing climate change negotiations under the UNFCCC and agreed in the Bali Action Plan (UNFCCC, 2007).

Disaster risk management and climate change adaptation could be realised through increased awareness and use of their synergies and differences, and by the provision of a framework for integration in areas of overlap between the two. (Venton and La Trobe 2008). The World Conference on Disaster Reduction (WCDR) held in Kobe (UN ISDR, 2005c), Hyogo Prefecture, Japan in 2005 and the Bali Action Plan both point to the need for incorporation of measures than can reduce climate change impacts within the practice of disaster risk reduction. Integration of the relevant aspects of disaster risk reduction and climate change adaptation can be facilitated by using the Hyogo Framework for Action (2005-2015) as agreed by 168 governments in Kobe (UN ISDR, 2005a).

7.1.2. Related Questions and Chapter Structure

Within the context of the overarching question – how can the experience with disaster risk management inform and help with climate change adaptation? – there are a series of other related issues to be addressed in this chapter in order to provide a basis for their closer integration. A first question concerns the rationale for disaster risk management and climate change adaptation at the international level. The issues of systemic risks and international security, economic efficiency, solidarity and subsidiarity are address in Section 7.2.

A second topic concerns the nature and development of institutions and capacity at the international level. This topic is explored in Section 7.3 concentrating on the Hyogo Framework for Action and the United Nations Framework Convention on Climate Change.

A third issue concerns the opportunities and constraints for disaster risk management and climate change adaptation at the international level. These include the matters of legal, financial, technology, risk transfer and cooperation, and the creation of knowledge, its management and dissemination. All are addressed in Section 7.4.

Considerations of future policy and research are addressed in Section 7.5.

The challenge of bringing lessons from disaster risk reduction to climate change adaptation takes on a different complexion at different temporal and spatial scales. The question of integration across scales is taken up in Section 7.6.

7.2. Rationale for International Action

This section examines the rationale for DRR and CCA interventions at the international level. Starting from the reality that risks of extreme weather and risk management interventions cross national borders, this section discusses the systemic nature of these risks and their effects on international security before turning to a discussion of the principles of efficiency, solidarity and subsidiarity as they have shaped international discourse, practices and legal obligations and responsibilities within existing frameworks and conventions.

7.2.1. Systemic Risks and International Security

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. 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 full extent of these impacts is not well documented. 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. 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. Relationships and connections involving the movement of goods (trade), finance (capital flows and remittances), and people (displaced populations) can have transboundary effects and extend to continents and indeed to the world as a whole. Moreover, actions in one country can have effects on the risks of another, for example, clearing forests in an upstream riparian country can increase flood risks downstream. 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).

Turning specifically to displaced persons, a recent UN report estimated that over 20 million people were displaced by sudden-onset climate-related disasters in 2008 compared to 4.6 million newly displaced because of conflict (Norwegian Refugee Council and Internal Displacement Monitoring Center, 2009). This report and others, however, acknowledge the difficulty of disentangling the drivers of migration, including climate change risks, rising poverty, spread of infectious diseases such as HIV/AIDS, and conflict (Myers, 2005; Morrissey, 2009; Guzman, 2009; Thomalla et al., 2006; Barnett, and Adger 2007; CIENS, 2007). 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). To the extent that weather extremes contribute to migration, it can result in a huge burden to the destination areas (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 continues to be a source of concern prompting the need for international intervention (Barnett and Adger, 2007; Heltberg et al., 2008; Kolmannskog, 2008; Warner et al., 2009; Tacoli, 2009).

The international impacts of climate-related disasters can extend beyond financial consequences, international trade and migration, and affect human security more generally. O'Brien et al., (2008) report on the intricate and systemic linkages between DRR, CCA and human security emphasizes the importance of confronting the societal context, including development levels, inequality and cultural practices. A further rationale for disaster risk reduction in the face of climate change at the international scale thus places emphasis on both equity issues and the growing connections among people and places in coupled social-ecological systems.

7.2.2. 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 inefficiencies in resource allocation brought about by missing and misaligned markets ((p. 467). International interventions are thus arguably justified on the basis of the principles of interdependence of the world economy and human security (discussed above) and the public good nature of many risk management actions, for example, implementing regional warning systems and collecting climate data. Tompkins and Adger (2005) and Berkhout (2005) discuss how some areas, such as water resources, change from being public to private depending on national regulations and circumstances,. Nevertheless, the principles of interdependence and public goods suggested by Stern and others (and which lead to inefficient allocation of resources) are widely adopted and shared within the literature on international responsibility (Stern 2007, Vernon, 2008; World Bank, 2010; Gupta et al., 2010).

Early warning systems (as an example of a public good) can depend on regional and international cooperation to secure the exchange of necessary data. 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), which benefit individuals, development agencies, governments and others paying the upfront costs for catastrophic risk coverage.

7.2.3. Solidarity

It is not only efficiency considerations that justify international interventions, but also solidarity with those least able to cope with the extreme impacts of climate change. In the words of the Millennium Declaration that was adopted by 189 nations- in September 2000: "*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 have a significantly higher chance of dying due to natural disasters, and the economic cost per disaster in terms of GDP is much higher than in OECD countries (Barnett et al, 2008). Increasing frequency, magnitude and spatial coverage of some climate extremes (see Chapter 3) mean losses can exceed the capability of many individual countries to manage the risk (Rodriguez et al, 2009). Many have concluded 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). Solidarity can take the form of ex ante interventions to reduce vulnerability and poverty, as well as ex post disaster response and assistance.

Weather extremes constrain progress towards meeting the Millennium Development Goals (MDGs) as expressed in the Millennium Declaration , especially the goal of eradicating extreme poverty and hunger (UNDP, 2002; Mirza, 2003; UNDP, 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. (2007) have shown that ex ante risk management strategies on the part of the poor commonly sacrifice expected gains, such as investing in improved seed, to reduce risk of suffering catastrophic loss, a situation perpetuating the "poverty trap". The poor can be subject to multiple exposure from climate change and other stresses 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. With growing globalisation the principle of solidarity is further enhanced as offers of 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). Examples include Johnsons and Johnson's provision of relief to disaster victims and Monsanto's efforts to teach impoverished farmers techniques for growing crops in periods of drought (Dunfee and Hess 2000).

Humanitarian assistance, although essential for upholding solidarity, 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).

Beyond a sense of common human concern, it is argued that countries contributing most to climate change have a "principled" obligation to support those who are most vulnerable and who have made a limited contribution to the creation of the climate change problem. This is the claim underlying the notion of Common but Differentiated

Responsibility (CBDR), which has emerged as a guiding principle of international environmental law (De Lucia, 2007) 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] (UNCED, 1992)

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 (see section 7.2.5). Farber (2007, 2008), Delink et al. (2009) and Grasso (2010) review potential arguments over who is responsible and who should pay for adaptation. From this literature, potential principles for allocation of responsibility have emerged including compensation to the victims a) by the beneficiaries of adaptation 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' from the impacts of climate change.

Another set of literature (e.g. Caney, 2010; Adger et al. 2009) frames equity issues around climate change in terms of "rights", namely the right 'not to suffer from dangerous climate change' or 'to avoid dangerous climate change' (Caney, 2008; Adger, 2004). The rights argument, which is highly relevant to international solidarity, can be extended to suggest that individuals and collectives have the right to be protected from risk and disaster imposed by others through the processes that lead to social exclusion, marginality, exposure and vulnerability. Climate change impacts jeopardise fundamental rights to life and livelihood (such as impacts on disease burden, malnutrition and food security). Caney (2010) also discusses a right 'not to be forcibly evicted' (p. 83) as a potential further undeniable right. 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, and can be taken to apply to climate related disasters only if 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 3.2.2).

7.2.4. Subsidiarity

Subsidiarity, as specifically articulated in Article 5 of the Treaty of Maastricht on European Union (The Maastricht Treaty, 1992), is based on the concept that centralized governing structures should only take action if deemed more effective or necessary than action at lower levels (Jordan, 2000; Craeynest, et al., 2010). The intent is to strengthen accountability and reduce the dangers of making decisions in places remote from their point of application (Gupta and Grubb, 2000). In Europe, the principle of subsidiarity implies, for example, that international or national level involvement in flood protection should only apply to cross-border catchments (Stoiber, 2006).While many regions and river basins are required to develop risk management flood plans, flood protection is predominantly a national (and in many countries, e.g., Germany and India), primarily a state responsibility.

The principle also recognizes that multi-level governance requires cooperation between all levels of government (Begg, 2008). As an example of this cooperation, 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 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. With a similar intent on another continent, in 2010 Central American presidents approved the Central American Policy for Integral Disaster Risk Management [reference to be supplied].

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 been assessed in detail by Verheyen (2005). 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 (OHCHR , 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 at an international level 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 insurance schemes, though at present it is unresolved as to whether this implies 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. At article 3.14, UNFCCC's Kyoto Protocol considers the establishment of insurance mechanisms.

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 *opinio 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 environmental risks (Trouwborst 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). This 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 Organisations in Disaster Relief (1995) and the Sphere Project for Humanitarian Charter 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 (Fidler, 2005). They are also limited in their application, since they are the creation of International NGO’s and are rarely recognised in the policies of National Governments. 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 the 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 are the development of 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

Given the foregoing rationale for international action based upon considerations of systemic risk and international security, economc efficiency, solidarity and subsidiarity as well as legal obligations and responsibilities, what international governance institutions currently exist and how do they contribute to the management of disaster risks at the international level? The number and vatiety of institutions is very large. A full survey and assessment is well beyond the scope of this chapter, although it is a task that might be useful to undertake. The instituional assessments made in this report concentrate on the Hyogo Framework for Action (HFA) and the UN Framework Convention on Climate Change (UNFCCC) in Sections 7.3.1 and 7.3.2 respectively. Section 7.3.3 provides some minimal information on other current actors, knowing that this does not do justice to the many other institutions and capacities whose work relates to disaster risk management and climate change adaptation at the international level.

The international governance of disaster risk reduction and climate change adaptation is shaped and informed by several international policy frameworks. The significance of these loosely connected frameworks lies in their shared values, goals and approaches, formally agreed by the vast majority of national governments. Together, the policy frameworks form the working agenda for actions to reduce disaster risk and adapt to climate change.

Among the many relevant frameworks and protocols administered by a host of United Nations and other international agencies, the most significant for this Special Report are the *Hyogo Framework for Action* (HFA), to reduce disaster risk, and the *United Nations Framework Convention on Climate Change* (UNFCCC), which includes adaptation to the adverse effects of climate change. Since both disaster risk reduction (DRR) and climate change adaptation (CCA) occur within a broader development context and are particularly relevant to the challenges facing developing countries, they are indirectly connected to a third important international framework: the *Millennium Development Goals* (MDGs).

The HFA and the UNFCCC were developed over different time frames by different UN agencies and without significant coordination. Since around 2005 however, governments have begun to encourage the international DRR and CCA communities to work together so as to avoid wasteful duplication, and to synchronise frameworks and approaches so as to create added value to current risk management initiatives. This IPCC Special Report is one example of the initiatives taken by governments. It is one of the first official products of the two communities working within different but related policy frameworks.

This section first introduces the HFA and the UNFCCC, including an overview of their respective objectives, legal nature and status of implementation. It then presents relevant international actors involved in implementing these two frameworks, as well as a summary of other relevant international policy frameworks and agencies.

7.3.1. The Hyogo Framework for Action (HFA)

7.3.1.1. Evolution and Description

The first major collective international attempt to reduce disaster impact, particularly within hazard-prone developing countries, took place in 1989 when the United Nations designated the 1990s as the International Decade for Natural Disaster Reduction (IDNDR) (Wisner et al., 2004). About 120 National Committees were established and in 1994, the World Conference on Natural Disaster Reduction was held in Yokohama, Japan. The conference produced the 'Yokohama Strategy and Plan of Action', providing policy guidance, with a strong technical and scientific focus.

In 2000, the IDNDR was followed by the United Nations International Strategy for Disaster Reduction (ISDR), which broadened the technical scope of the IDNDR to include increased social action, public commitment and linkages to sustainable development. The ISDR system promotes tools and methods to reduce disaster risk while encouraging collaboration between disaster reduction and climate change. The ISDR secretariat provides information and guidance on disaster risk reduction and has increasingly widened its focus to embrace adaptation to climate change. The strategy undertakes global reviews of disaster risk and promotes national initiatives to reduce risks. A key function is to facilitate the compilation, exchange, analysis and dissemination of good practices and lessons learned in disaster risk reduction (refer to 7.4.5 on knowledge creation, management and dissemination).

In January 2005, just three weeks after the Indian Ocean tsunami, the World Conference on Disaster Reduction (WCDR) was held in Kobe, Japan. 168 governments supported the *Hyogo Framework for Action (HFA) 2005–2015: Building the Resilience of Nations and Communities to Disasters*. The HFA was unanimously endorsed by the UN General Assembly (UN ISDR, 2005a). The HFA is not a binding agreement: the signatory governments simply agreed and adopted the framework as a set of recommendations to be utilised voluntarily. In international law it can be described as 'soft law'. However, since the HFA was adopted just after the tsunami it had greater international visibility and a sense of moral obligation.

Some regard the voluntary nature of the HFA as a useful flexible commitment largely based on self-regulation and trust, while others regard this as its inherent weakness. Thus Pelling comments: 'not surprisingly given the vested interests of the dominant voices in the international community for the status quo, the framework is limited' (Pelling, 2011, p.44).

The main instruments to encourage HFA applications are the HFA Monitoring Service on Preventionweb acting mainly as a guidance tool and facilitating some peer pressure (refer to 7.4.5). Further tools include the reports to the sessions of the Global Platform for DRR and the regional platforms for DRR and other similar mechanisms. The HFA is also discussed in Chapter 1.3.6 and Chapter 6.3.2.1.

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 Priorities for Action PFA's

i. Ensure that DRR is a national and local priority, with a strong institutional basis for implementation
ii. Identify, assess and monitor disaster risks and enhance early warning
iii. Use knowledge, innovation and education to build a culture of safety and resilience at all levels
iv. Reduce the underlying risk factors
v. Strengthen disaster preparedness for effective response at all levels.

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' (UNISDR 2005a).

7.3.1.2. Status of Implementation

As a result of the adoption of the HFA, and the development of performance indicators, global efforts to address DRR have become more systematic. In 2009, the first biennial Global Assessment Report on Disaster Risk Reduction (GAR) was released and on the same year the Global Network of Civil Society Organisations for Disaster Reduction also released a report on the performance of the HFA (GNCSODR 2009). The GAR report found that since the adoption of the HFA, progress towards decreasing disaster risk is varied across scales. This variation is based on national agencies self-assessment of progress against the indicators defined in the HFA and hence is 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 since the GAR findings continued to state that current DRR governance arrangements do not allow for the full integration of risk reduction into development. Further, both GAR and the Global Network of Civil Society Organisation for Disaster Reduction (GNCSODR) noted that at national and international levels, policy and institutional frameworks for climate change adaptation and poverty reduction are faintly connected to those for DRR. Ecosystem management approaches can provide multiple benefits, including risk reduction and thus be a central part of such strategies. The GNCSODR observed that 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. 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 (UNISDR, 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 geographical 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 systemic risk (UN ISDR, 2009b).

The GNCSODR which evaluated the progress of HFA on each of its five Priorities for Action (PFA) found that the lowest level of progress across all the five PFA's was at the lowest scale i.e in community participation in decision making on DRR (GNCSODR 2009). 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 (see 7.4.5 on knowledge creation, management and dissemination). 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. Nevertheless, countries are making significant progress in strengthening capacities, institutional systems and legislation to address deficiencies in disaster preparedness and response (GNCSODR, 2009; UN ISDR, 2009a).

However, it is important to reflect on the reality that the three methods noted above to review international progress in risk reduction: country progress reports, the Global Assessment Reports of 2009 and 2011, and the reports of the Global Network of Civil Society Organisations do not constitute fully objective, scientific peer review assessments. The country progress reports and the GAR are both internally produced documents, thus having the status of grey literature These country HFA Reports are online at http://www.preventionweb.net/english/hyogo/progress/?pid:73&pih:2. The Global Network's publications are fully independent from the UN and Governments, but make no claim to be scientifically accurate assessments. However, in 2010 at the mid-point in the HFA, the UN Secretary General has reported that 'risk reduction is still not hardwired into the "business processes" of the development sectors, planning ministries and financial institutions' (UNGA, 2010 p.5).

The measurement of performance in the implementation of DRR was a matter of considerable debate when the HFA was drafted. The consensus was for the final text not to include targets or indicators of progress, but countries were encouraged to develop their own guidelines to monitor their own progress in reducing their risks. To assist this process in 2008 ISDR published guidance notes on 'Indicators of Progress' (UN ISDR 2008). This provided the template for self assessment that is used in national reports. While there is an obvious value in 'self-assessment' as a learning experience, in the absence of external, objective evaluation, inevitable doubts will always remain concerning such internal reporting on actual progress with DRR and CCA.

In preparing for the mid-term review of the HFA the UN ISDR secretariat commissioned a desk review of literature to form 'a baseline of the disaster risk reduction landscape' 47 key documents were identified, mainly consisting of reports from ISDR offices and partner organisations: NGO's, and International Development Banks (http://www.preventionweb.net/english/hyogo/hfa-mtr/?pid:73&pil:1).

However, none of these documents are peer reviewed academic studies. In preparing this report, despite an extensive search, the lead authors have not located any peer reviewed independent research into the effectiveness of the HFA programme from 2005–2011. Enquiries were made to senior staff in ISDR to identify any scientific peer reviewed assessments of the performance of the HFA. In response the authors of this report were advised that while they did not know of any peer reviewed academic papers, there was "a need to distinguish between lack of peer reviewed academic work and lack of progress". It was noted that a system had been put in place with indicators, self-assessment by Governments and analysis every two years in the Global Assessment Review as the Global Platform Sessions that brought a regional dimension to performance assessment. ISDR staff believed that these mechanisms effectively monitored progress and provided a wealth of information.

Whatever method is adopted to monitor progress with risk reduction and climate change adaptation (internal or external, self-assessment or peer review), the implicit problems to face in the measurement of DRR and CCA before a disaster event must be recognised. It is not easy, even with detailed objective scientific measurement, to accurately determine whether a given structural or non-structural measure will actually provide the necessary level of protection to people and property under extreme hazard loads. Structural tests can be carried out and simulation exercises can be usefully conducted to test warning systems or the effectiveness of preparedness, but at best such performance tests can only approximate to disaster reality. The ultimate test of DRR and CCA applications will inevitably need to await the impact of the next disaster. But this limitation does not remove the requirement to monitor and measure progress in an objective scientific manner to the upper limits of existing knowledge (Davis, 2004). In early 2011 the full mid term review of progress with the HFA will be published.

["Notes to readers: During February 2011 after the completion of this Second Order Draft, the ISDR intends to publish a Mid-Term Review of HFA and this will be debated at the Third Global Platform in Geneva from May 8-13. We will endeavour to take this report into account in the final draft of this chapter to be written between May 20 and August 5, 2011.]

7.3.2. The United Nations Framework Convention on Climate Change

7.3.2.1. Evolution and Description

The United Nations Framework Convention on Climate Change (UNFCCC) is an intergovernmental treaty aimed at addressing climate change. Its ultimate objective as stated in Article 2 is "to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". (UN 1992) The UNFCCC was negotiated from February 1991 to May 1992, and opened for signature at the UN Conference on Environment and Development in Rio de Janeiro in June 1992. It entered into force on 21 March 1994, and since 1995 the Conference of the Parties (COP) to the UNFCCC has met in yearly sessions. The rules, institutions and procedures of the UNFCCC have been described in detail elsewhere (e.g., Yamin and Depledge 2004).

An important part of the UNFCCC and the subsequent negotiations about its implementation concern the mitigation of climate change: all policies and measures aimed at reducing the emission of greenhouse gases such as CO_2, or at retaining and capturing them in sinks such as forests, oceans and underground reservoirs. Adaptation to climate change was initially given little priority, although it is subject to various commitments in the UNFCCC (see Box 7-1) which when taken together acknowledge the systematic nature of climate change risks and the relevance of the principles of economic efficiency, solidarity and subsidiarity in adaptation.

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Box 7-1 . Commitments on Climate Change Adaptation as Included 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.'

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The *Kyoto Protocol*, agreed at COP3 in 1997 and in force since 2005, sets binding targets for 37 industrialised countries and the European Union for reducing greenhouse gas emissions by an average of 5% by the period 2008–2012. Adaptation is all but absent in the Kyoto Protocol, with one exception. Article 12.8, on the Clean Development Mechanism, provides the basis of what later became the Adaptation Fund.

7.3.2.2. Status of Implementation

There is no overall assessment of progress on adaptation under the UNFCCC in the way that the ISDR has made assessment of progress under the HFA in the Global Assessment Report (GAR) Parties to the UNFCCC are required however to make submissions (National Communications) on the implemetation of the Framework Convention incuding adaptation. There is however no common template for submissions on adaptation and these vary widely in content and frequency making an assessment problemmatic.The annual meetings of the COP allow countries to assess their progress towards meeting their commitments under the UNFCCC, and to negotiate and adopt new decisions for further implementation. By December 2010 there were 194 Parties to the UNFCCC: 193 countries and one regional economic integration organisation (the European Union).

During the 1990s adaptation received little attention in the UNFCCC negotiations, reflecting a similarly low level of attention to adaptation from the academic community at the time. The profile was raised in 2001 with the publication of the IPCC Third Assessment Report, which contained the chapter ‘Adaptation to Climate Change in the Context of Sustainable Development and Equity’ (Smit and Pilifisova, 2001). Also in 2001, COP7 adopted a decision (5/CP.7) that outlined a range of activities that would promote adaptation in developing countries, including the preparation of National Adaptation Programmes of Action (NAPAs) by least developed countries. To this end, COP7 established three funds with which adaptation in developing countries could be supported, namely the Least Developed Countries Fund (LDCF), the Special Climate Change Fund (SCCF), and the Strategic Priority on Adaptation (SPA) under the Trust Fund of the Global Environment Facility (GEF). In addition, COP7 took the first steps towards making operational the Adaptation Fund (see Section 7.4.2 for more information on the international financing of climate change adaptation).

Since 2001 a number of successive decisions have give increasing priority to climate change adaptation under the UNFCCC. Decision 1/CP.10 built on decision 5/CP.7; it reiterated the need for support for adaptation in developing countries and started a regional consultation process. Decision 2/CP.11 then established the *Nairobi Work Programme on impacts, vulnerability and adaptation to climate change*, which originally ran from 2006 to 2010 and is now undergoing review and extension. The objective of the Nairobi Work Programme is to assist all Parties, in particular developing countries, (*i*) to improve their understanding and assessment of impacts, vulnerability and adaptation to climate change, and (*ii*) to make informed decisions on practical adaptation actions and measures to respond to climate change on a sound scientific, technical and socio-economic basis, taking into account current and future climate change and variability. The Nairobi Work Programme is implemented by Parties, intergovernmental and non-governmental organisations, the private sector, communities and other stakeholders. Several of the nine work areas of the Nairobi Work Programme are relevant to DRR as well as CCA, in particular ‘climate-related risks and extreme events’ and ‘adaptation planning and practices’.

With decision 1/CP.13 (also known as the *Bali Action Plan*), agreed on in December 2007, the COP launched “a comprehensive process to enable the full, effective and sustained implementation of the Convention through long-term cooperative action, now, up to and beyond 2012, in order to reach an agreed outcome and adopt a decision at its fifteenth session” in Copenhagen in December 2009 (COP15). The Bali Action Plan attached equal weight to mitigation and adaptation, and identified technology and finance as the key mechanisms for enabling developing countries to respond to climate change. It recognised the need for action to enhance adaptation in five main areas:

- International cooperation to support urgent implementation of adaptation actions, through vulnerability assessments, prioritisation of actions, financial needs assessments, capacity building, and integration of adaptation actions into sectoral and national planning
- Risk management and risk reduction strategies, including risk-sharing and transfer mechanisms such as insurance
- Disaster reduction strategies and means for addressing loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to climate change
- Economic diversification to build resilience
- Strengthening of the catalytic role of the UNFCCC in encouraging multilateral bodies, the public and private sectors, and civil society to build on synergies among activities and processes in order to support adaptation in a coherent and integrated manner.

In the event, no agreed outcome was reached at COP15, and no comprehensive decision was adopted that included these five issues. Instead, the COP decided to take note of the Copenhagen Accord, a non-binding political declaration about which there was no consensus among parties, and which provides considerably less substance on adaptation than the Bali Action Plan (Klein, 2010).

Most recently, decision 1/CP.16 (part of the *Cancun Agreements*) established the Cancun Adaptation Framework. It invites all Parties to enhance action on adaptation by undertaking nine activities related to planning, implementation, capacity strengthening and knowledge development, including ‘Enhancing climate change related disaster risk reduction strategies, taking into consideration the Hyogo Framework for Action where appropriate; early warning systems; risk assessment and management; and sharing and transfer mechanisms such as insurance, at local, national, subregional and regional levels, as appropriate.' In addition, decision 1/CP.16 established (*i*) a process to enable least developed countries and other developing countries to formulate and implement national adaptation plans; (*ii*) an Adaptation Committee that will, among other things, provide technical support, share relevant information, promote synergies, and make recommendations on finance, technology and capacity-building required for further action; (*iii*) a work programme in order to consider approaches to address loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to the adverse effects of climate change.

Decision 1/CP.16 also established a Technology Mechanism, consisting of a Technology Executive Committee and a Climate Technology Centre and Network. The Technology Mechanism should accelerate action at different stages of the technology cycle, including research and development, demonstration, deployment, diffusion and transfer of technology in support mitigation and adaptation. Finally, decision 1/CP.16 established the Green Climate Fund as a new entity operating the financial mechanism of the UNFCCC under Article 11 (see Section 7.4.2).

The above unfolding of international adaptation policy under the UNFCCC shows the increasing prominence of adaptation in the negotiations, and the increasing level of detail and concreteness of the relevant COP decisions. It also shows that adaptation under the UNFCCC is increasingly linked with disaster risk reduction, with the Hyogo Framework for Action explicitly mentioned in the Cancun Agreements. Yet, this unfolding, from decision 5/CP.7 to decision 1/CP.16, has taken ten years, and some observers have argued that progress at the international level is too slow compared to the urgent need for action on the ground [reference to be supplied].

7.3.3. Current Actors

7.3.3.1. International Coordination in Linking DRM and CCA

Given the wide range of actions and actors that are considered necessary by those involved to carry out DRM and CCA, and to link them to each other, effective international coordination is essential. Overall, there are weaknesses in the current systems; the 2009 Global Assessment Report on Disaster Risk Reduction states that: "Efforts to reduce disaster risk, reduce poverty and adapt to climate change are poorly coordinated."(UN ISDR, 2009a).

The main coordination mechanism from the DRM side is the ISDR, designed to create a system of partnerships to support 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 across scales, the national governments play the most important roles, including 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 play a supporting role, including, for example, including promotion of DRR programmes and integration into development planning, and capacity building (UN ISDR, 2005b). The UN ISDR Secretariat supports and assists the ISDR system. It is responsible for facilitating the coordination of actions at the international and regional levels; developing indicators of 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 (UN ISDR, 2009c). As a result, ISDR system appears to be in line with the principle of subsidiarity.

UNISDR has made specific efforts to link DRM and CCA, through advocacy of the role of DRR in climate change adaptation, and support for scientific reviews of the linkages (including this report). Independent evaluation of the UNISDR confirms its overall effectiveness, particularly in advocacy and awareness raising, and in establishing global and regional platforms, and specifically highlights its strong contribution to mainstreaming DRR into the climate change debate. However, it also highlights difficulties, including lack of definition of comparative advantage within CCA implementation, and the needs to balance the focus and resources spent on DRR in climate change versus the broader DRR concept. The same review also illustrates challenges in coordination for implementation, particularly the need for effective coordination with UN Country Teams, the World Bank and other relevant partners at country level, and in the full implementation and sustainable follow-up of new initiatives (Dalberg, 2010).

The main global coordination mechanism from the CCA side is The Nairobi Work Programme (NWP) of the UNFCCC (UNFCCC, 2010a) (Refer to 7.3.2.2 on implementation of UNFCCC). The NWP functions mainly as a forum for interested parties to specify their own contributions to CCA through "action pledges", and for sharing, synthesis and dissemination of information. DRR is well represented within the NWP, which identifies DRR as one of its 14 specified adaptation delivery activities, with an associated "call to action" for strengthened work in areas such as linking DRR and CCA, risk mapping, and cost-benefit analysis of adaptation options. Out of the 137 action pledges made by partners 59 include a component of DRR. Formal evaluation of the NWP is only now being carried out, so as yet there is no independent assessment of the degree to which it has supported changes in policy and practice as well as information exchange. The work of the NWP is clearly appreciated by UNFCCC Parties as the main stakeholders, and its mandate was extended in 2010 (UNFCCC, 2010b).

7.3.3.2. International Technical and Operational Support

DRM and CCA are now beginning to be linked not only in international coordination activities, but also in mechanisms for international technical and operation support.

7.3.3.2.1. Climate services for DRR and CCA

National Meteorological and Hydrological Services (NMHSs) are the primary source of observed and forecast on weather-related hazards, that is a critical component of planning for disaster risk management, as well as longer term projections to support climate change adaptation. These national services also constitute the members of the World Meteorological Organization (WMO), which serves to set international standards and coordinate among the members, as well as supporting several relevant international programmes, including a Disaster Risk Reduction and Service Delivery Branch and a Climate Prediction and Adaptation Branch.

In recent years, a number of studies have identified weaknesses in the way in which the large amount of potentially relevant weather climate information that is available from NMHSs at national and international level is incorporated into development decisions, particularly in the most vulnerable countries. For example a ‘gap analysis’ of this issue in Africa identified gaps in (i) Integrating climate into policy, (ii) Integrating climate into practice, (iii) Climate services, and (iv) Climate data, concluding that "the problem is one of "market" atrophy: negligible demand coupled with inadequate supply of climate services for development decisions.' (IRI, 2006). Studies on specific sectors (e.g. health (WHO, 2005)), or at local level (Vogel and O'Brien, 2006) conclude that the main deficit is not in generation of data, but in knowledge management, requiring greater attention to creating effective mechanisms for decision-makers and providers of weather and climate information to interact to manage climate risk.

In response to the need for a comprehensive approach to climate variability and change, and the drive for more demand-driven climate services the World Climate Conference-3 agreed in 2009 to begin development of a Global Framework on Climate Services (GFCS) (WMO, 2010). This has a goal of “the development and provision of relevant science based climate information and prediction for climate risk management and adaptation to climate variability and change, throughout the world.” The framework therefore explicitly links climate variability (most relevant to DRR), in the context of climate change (most relevant to CCA), and support for risk management decisions (common to both). The Global Framework has four major components: a User Interaction Mechanism; World Climate Services System; Climate Research; and Observation and Monitoring. The initiative will focus on improving access and operational use of climate information in the most vulnerable countries, and will operate across international, regional and national levels. While the GFCS is not yet operational, and is therefore some way from being evaluated, the principles and focus of the initiative are well suited to linking DRM and CCA across international and other scales.

7.3.3.2.2. Technical and operational support from global civil society

Many international civil society organizations are now beginning to integrate climate change adaptation activities into long standing programmes on disaster risk management and humanitarian response.

One of the best-best established examples of civil society providing technical support to CCA and DRM integration is the Red Cross/Red Crescent Climate Centre in the Netherlands. This Centre seeks 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.

The various international civil society organizations working on DRR, are now also beginning to coordinate their operational support, and to make explicit links to CCA (UN ISDR, 2010). A Global Network of Civil Society Organisations for Disaster Reduction was launched in 2007, and constitutes over 300 Organizations across 90 countries. It has three objectives of (1) Influencing DRR Public Policy Formulation (Development), (2) Increasing Public Accountability for Effective Policy Administration (Implementation), and (3) Raising resources and political will for community-based DRR (Mobilisation). One of the five core strategies of the Global Network is to develop synergies between DRR – Climate Change to address underlying risk factors (sustainable development), including adapting local level DRR monitoring infrastructure for climate adaptation, and input to the COP negotiations. Given the recent launch of the initiative there is no evaluation of effectiveness so far.

7.3.3.3. International Finance Institutions and Donors

7.3.3.3.1. 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 (SCCF) and the Least Developed Countries Fund (LDCF). 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.

7.3.3.3.2. World Bank Global Facility for Disaster Reduction 2006-2015

The Global Facility for Disaster Reduction and Recovery (GFDRR) is a partnership of the ISDR system to support the implementation of the Hyogo Framework for Action (HFA). The GFDRR's mission is to mainstream disaster reduction and climate change adaptation in country development strategies. The Facility is made operational by the World Bank on behalf of the participating donor partners and other partnering stakeholders. It supports international collaboration, and provides technical and financial assistance to high risk low- and middle-income countries with the key objective for mainstreaming risk reduction into national development policies, plans and strategies to achieve MDGs.

Independent evaluation of the GFDRR illustrates the strengths and challenges of international collaboration in DRM and CCA. The facility has mobilized significant funds (over US$240 million in contributions and pledges from 2006-2009). It is also considered relevant and responsive to stakeholders, technically skilled, including within the context of climate change. Overall, it is considered to play a unique role in advancing scientific, economic and policy understanding of disaster risk reduction, and helping to bridge knowledge, policy, and practice in DRR services. However, important challenges remain in scaling up activities to the necessary level for a comprehensive response. At this early stage of development, the scale of the resources are remain considerably less than required, partnerships and policy integration at national level are uneven, and tools to ensure efficiency in monitoring and evaluation are not fully functional. Despite these challenges, the facility is considered to have achieved important progress on the ground, and to be implementing the necessary steps to improve function and to scale up implementation (Universalia_Management_Group, 2010).

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Box 7-2. DRM and CCA in the Context of International Development

Vulnerability to extreme weather and to gradual climate change is strongly conditioned by socio-economic development, including income levels and distribution, and supportive institutional frameworks, and the capacities of specific sectors. Conversely, 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). The objectives of climate change adaptation, disaster risk reduction, and sustainable development, are therefore intricately linked, and while the HFA and UNFCCC are the main international frameworks for CCA and DRR, a wider range of other governance and institutional mechanisms have a major influence. These range, for example, from the agreements of the World Trade Organization (affecting development and potentially technology transfer for adaptation) the International Health Regulations (affecting the way that epidemics of climate-sensitive infectious diseases such as cholera are managed across borders), and codes of practice of international humanitarian organizations (such as the Red Cross Code of Conduct).

The most important framework for overall development is the Millennium Declaration, and the associated Millennium Development Goals (MDGs). These have been agreed by all members of the United Nations as well as 23 international organisations, with a target date of 2015. These are supported by international aid agreements, such as the Multilateral Debt Relief Initiative to cancel US$40-55 million dollars worth of debt, and the commitment of economically advanced countries to commit 0.7% of Gross National Income to Overseas Development Aid. The eight MDGs break down into 21 quantifiable targets that are measured by 60 indicators [Reference to be supplied].

Neither DRM nor CCA are explicitly covered in the MDGs. However, they are strongly linked in practice. First, if disasters occur they can set back progress across many of the goals. Second, progress towards the MDGs can help to increase resilience to extreme weather events, and to climate change. Linking CCA and DRM with the MDGs is therefore important for the coherence of international development, and the target date of the Hyogo Framework for Action was synchronized with the intended completion of the Millennium Development Goals (MDGs) by 2015.

While there are exceptions, the majority of the least developed countries, particularly in sub-Saharan Africa, are currently off-track to reach most of the MDGs. This has been attributed in part to financial, structural and institutional weaknesses in the affected countries, and also by failure of most developed countries to reach the 0.7% aid target. Failure or delays in reaching the MDGs are therefore likely to be both a cause and a consequence of vulnerability to extreme weather and climate change Reference to be supplied].

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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 section 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 obligations – 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 experiences challenges in 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). The application of international refugee law, as codified in the 1951 Convention relating to the Status of Refugees, to those who cross international borders due to climate-induced migration is complex and limited (UNHCR, 2009). 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 future opportunity 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. Expanding the interpretation and application of existing international law, and the introduction of new law for disaster response and climate change adaptation are both 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" is also 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. 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; UNDP, 2007; OECD, 2008). Several international organisations have made calculations of the future cost of adaptation in developing countries, albeit based on rough assumptions and inconsistent timelines (shown in Table 7-1).

[INSERT TABLE 7-1 HERE:
Table 7-1: Estimated Annual adaptation costs in developing countries. Sources: Human Development Report, UNDP (2007); Economic Aspects of Adaptation to Climate Change: Costs, Benefits, and Policy Instruments, OECD (2008)]

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 (Mitchell et al 2008).

The GEF manages the Least Developed Countries Fund (LDCF), the Special Climate Change Fund (SCCF) and the Strategic Priority on Adaptation (SPA) (Refer to 7.3.2.2 on implementation of UNFCCC). Concerns are increasingly voiced at all levels 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 (Mitchell 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 as opposed to funds for DRM might 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 Reference to be supplied]. 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 (UNFCCC, 2009b), 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).

7.4.3. Technology Transfer and Cooperation

7.4.3.1. 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. The sustainability, operation and maintenance of technologies can be challenging in many developing countries due to lack of resources, human capacity and cultural differences. Moreover, technology transfer is complex and requires capacity building as well as a client focus as opposed to a developer focus (O'Brien et al. 2007). 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 technologies for adaptation 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 technologies for adaptation 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 of 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 (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 includes 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. Structural measures are localized solutions and there is a need for localized information such as their environmental and hydrologic impacts. In addition there are 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). It is also important to integrate technology transfer efforts for CCA and DRR needs with sustainable development efforts.

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 7-3). Some other types of technologies are more recent, involving advanced materials science, perhaps, or satellite remote sensing. The UNFCCC report (2006b) provides an overview of the old and the new technologies available in adapting to changing environments, including climate change.

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Box 7-3. Examples of Technologies for Adaptation 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 models held appropriate by local experts. 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 7-3 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). There exits a great deal of diversity among these institutions and they differ significantly in terms of operating scales, such as small to medium to large and spatial scales such as local to national to international. Differences also exist in terms of their sectoral involvement such as agriculture, water, forestry, transport etc. and in their status as formal (*e.g.*, Ministry or Department of Environment, NAPA Secretariat) or informal (*e.g.*, a local village community). Formal institutions can respond to adaptation needs and challenges with policies, plans, guidelines resource allocation etc while informal institutions often respond to specific adaptation challenges such as drought, flood or a cyclone as self-organised and self-motivated systems. There exits a range of institutions in between these two extremes with 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).

7.4.3.2. 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 particularly important for adaptation to weather-related extreme events as well:

- 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 improve the 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. Downscaling projections from global climate models could provide useful information about the changing risks. It is important to note that, to the extent it is possible, early warning 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 technical components. (The focus on technology here does not negate the importance of social and communication aspects of early warning.) The use of GIS in the support of emergency operations in the case of both weather and 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 (see Chapter 3, Section 3.2.3 for details on downscaling regional climate models).

Space technologies (such as Earth observation, satellite imagery, real time application of space sensors, mapping) are important in the reduction of disasters, including extreme weather events such as drought, flood and storms (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. A good example of application of space technology at international scales and early warning is the WMO-National Oceanic and Atmospheric Administration-USAID-Hydrologic Research Center initiative on global flash flood guidance. The system uses global data produced by a global center, downscales the global information to regional products which are sent to national entities for further downscaling at national level and then disseminated to users and communities (WMO, 2007, 2010). It should also be noted that there are existing capabilities within some particularly exposed developing countries (such as India, Bangladesh, China, Philippines) with well-developed remote-sensing capabilities of their own, or existing arrangements with other space agency suppliers.

Support for relief agencies and governments depend, among other factors, 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 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. Transferring these technologies and the related know-how is important for building capacities in CCA and DRM in countries where they are still missing.

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. 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 WINDS (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. This aspect of 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. In addition to specific technology components, early warning systems (EWSs) should promote an integrated approach to link technology to population at risk. The weakest part of most of the early warning system is lack of linkages of systems components. Therefore EWS components ranging from collection of hydro-meteorological data, forecasting on how the nature will response (e.g. weather or flood forecasting) to communicating information (or warnings) to decision makers (sectoral users or communities) timely, and disseminating information to population at risk and community actions should be linked closely.

Natural hazards research has advanced to address a major challenge 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 (Groat 2004). The issue of tracking floods may be taken as an example of that. This indicates the importance in natural hazards research of 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 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.

7.4.3.3. 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). These factors are also important in transferring technologies for adaptation.

UNFCCC (2005) addresses the development and transfer of environmentally sound technologies for adaptation to climate change: such as the needs for, the identification and evaluation of technologies for adaptation to climate change, and financing their transfer. Cost is one of the main barriers in technology transfer; therefore innovative financing for the development and transfer of technologies is needed. Potential sources of funding for technology transfer include 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 (Refer also to 7.3.3.3 on International Finance Institutions and Donors). The GEF funds for adaptation activities include the Strategic Priority on Adaptation (SPA) trust fund, the LDC Fund and the SCCF. In addition, the GEF is providing secretariat services to the Adaptation Fund Board under the Kyoto Protocol (see also 7.4.2 on Financing). 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 (2009) developed the Screening Tool ADAPT (Assessment & Design for Adaptation to Climate Change: A Prototype Tool), a software based tool for assessing development projects for potential sensitivities to climate change. The tool combines climate databases and expert assessments of the threats and opportunities arising from climate variability and change. As of 2010, the knowledge areas covered by the tool cover: agriculture and irrigation in India and sub-Saharan Africa and, for all regions, various aspects of biodiversity and natural resources. Both conventional and innovative options for financing the transfer of technologies for adaptation might be explored. As conventional options the GEF funds (SPA, LDC Fund, and SCCF) 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).

The literature clearly shows that the transfer of technologies for adaptation lags behind the transfer of mitigation technologies in terms of the scales of attention and funding. Funding transfer and funding mechanisms for technologies that help reduce vulnerability to climate variability, particularly to whether-related extreme events appear to be an important for both CCA and DRM.

7.4.4. Risk Sharing and Transfer

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 (as discussed in chapter 6.3.3.3.) for governments of vulnerable countries that do not wish to rely on ad hoc and often insufficient post-disaster assistance.

Experience shows that the international community can play a role in enabling individual, national and international risk sharing and transfer strategies, and this discussion identifies successful practices, or value added, as well as constraints on this role.

7.4.4.1. International Risk Sharing and Transfer

Risk transfer (usually through formal means) and risk sharing (usually informal with no payment) is recognized by the international community as an integral part of DRM and CCA. The 2005 Hyogo Framework for Action calls on the disaster community "to promote the development of financial risk-sharing mechanisms, particularly insurance and reinsurance against disasters" (UN ISDR, 2005a: 11). Similarly, the 2007 Bali Action Plan calls for 'consideration of risk sharing and transfer mechanisms, such as insurance' as a means to address loss and damage in developing countries particularly vulnerable to climate change (Decision 1/CP.13, Bali Action Plan). The Plan strengthens the mandate to consider insurance instruments, as set out by Article 4.8 of the UN Framework Convention on Climate Change (UNFCCC) and Article 3.14 of the Kyoto Protocol. In response, two proposals for including insurance in an adaptation regime have recently been put forward (MCII, 2008; AOSIS, 2008).

Often by necessity risk sharing and transfer is international (see sections 5.5.2.2 for definitions). Local and national pooling arrangements (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 arrangement for sharing and transfer 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, UN ISDR, 2005b; 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.

7.4.4.2. International Risk Sharing and Transfer Mechanisms

This section reviews international mechanisms for sharing and transferring risk, including remittances, post-disaster credit, insurance and reinsurance, alternative insurance mechanisms, and regional pooling arrangements.

7.4.4.2.1. Remittances

Remittances, transfers of money from foreign workers or ex-pat communities to their home countries, make up a large part of informal risk sharing and transfer, even exceeding official development assistance. In 2006, the official worldwide flow of remittances was estimated at more than $250 million, and unrecorded flows 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; Mahapatra et al., 2009). Payments can be sent through professional money transfer organizations, but often these channels break down and remittances are carried by hand (Savage and Harvey (2007). While simple in concept, remittances 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 between 2.5% and 40% (DFID, 2005). Information pertinent to the transfer is often obscure or in an unfamiliar language, and, transfers across some borders have been complicated due to initiatives taken by developed nations to counter international money laundering and financing of terrorism (Fagen and Bump, 2007). Finally, a major problem is difficulties in communicating with relatives abroad, 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. (Pickens et al., 2009; DFID, 2005)

7.4.4.2.2. Post-disaster credit

As one of the most important post-disaster financing mechanisms, credit provides governments and individuals with resources after a disaster, yet with an obligation to repay 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 recovery and reconstruction with 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). With the growing importance of pre-disaster planning, a recent innovation on the part of international organizations is to make 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 given increased demand that tempts relaxed loan conditions or even debt pardoning. This risk is particularly acute in vulnerable regions. Recognizing the need for a risk transfer instrument to help MFIs remain solvent in the post-disaster period, 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) (UNFCCC, 2008). Located in Costa Rica, ELF provides needed and immediate post-disaster liquidity at low rates to MFIs across the region.

7.4.4.2.3. 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 insurance and reinsurance markets attracting capital from international investors, insurance has become an instrument for transferring disaster risks over the globe. The market is highly international in character. In the period 2000-2005, for example, U.S. insurers purchased reinsurance annually from more than 2,000 different non-U.S re-insurers (Cummins and Mahul, 2009: 115) Yet, the market is unevenly distributed. From 1980 through 2003 insurance covered four 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 is playing an active role in enabling insurance in developing countries, particularly by supporting micro- and sovereign (macro) insurance initiatives. The following four examples illustrate this role:

- 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 significant challenges to scaling up current operations. Lack of data, regulation, trust and knowledge about insurance, as well as high transaction costs, are some of the barriers (Hellmuth, 2009; Miamidian, 2005).

Insurance and other risk financing instruments are particularly effective for adaptation, when used in conjunction with or when creating incentives for 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).

7.4.4.2.4. 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 natural hazard event 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. Over 90% of cat bonds are issued by insurers and reinsurers in developed countries. Although it is still an experimental market, 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 insure its catastrophe fund FONDEN against earthquake and (in 2009) hurricane risk, and thus to defray costs of disaster recovery and relief (Cardenas et al., 2007). The World Bank provided technical assistance for these transactions. Although the transaction costs of the Mexican cat bond were large, and basis risk and counterparty credit risk are further impediments to their success, 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 government treasuries are vulnerable to catastrophic risks, and post-disaster financing strategies generally have high opportunity costs for developing countries.

International and 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 the important role that securitized instruments can play in providing a backup for humanitarian aid when disasters strike.

7.4.4.2.5. International risk pools

Regional catastrophe insurance pools are a promising innovation that can enable highly vulnerable countries, and especially small states, to more affordably transfer their risks internationally. By pooling risks across individual countries or regions, catastrophe insurance pools generate diversification benefits that reduce insurance premiums. By accumulating reserves over time, pools are able to increase risk retention and eventually insurance premiums., Finally, there is growing empirical evidence that catastrophe insurance pools have been able to diversify inter-temporally and thus dampen the volatility of the reinsurance pricing cycle and offer secure premiums to the insured governments (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 commensurate with their exposure 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 mitigate 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.

7.4.4.3. 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 (Cummins and Mahul, 2009);
- *Supporting public goods* for development of risk market infrastructure, for example, donors might consider funding the 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 (Hess, 2007), and the World Bank provided technical assistance for the Mexican CAT bond (Cardenas et al., 2007).
- *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 (Pickens et al., 2009; DFID, 2005);
- *Financing risk transfer*, as examples, the Bill Gates Foundation subsidizes micro-insurance in Ethiopia (Suarez et al., 2009); the World Bank provides low-cost capital backing for the Mongolian micro-insurance program (Skees, et al., 2008); Swiss SECO and IDB provide low-interest credit to the ELF (UNFCCC, 2008), and many countries have contributed to the CCRIF fund (Cummins and Mahul, 2009).

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 7.2.3 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 7.2.2 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. (see, e.g., Skees, 2001; Gurenko, 2004)

Recognizing these concerns, there are important and valid reasons for interfering in catastrophe insurance and other risk-financing markets in specified contexts (see discussions by 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. Knowledge Creation, Management, and Dissemination

A close integration of DRR and CCA and their mainstreaming into developmental agendas for managing risks across scales calls for multiple ways of knowledge acquisition and development, management, sharing and dissemination at all levels. Knowledge on the level of exposure to hazards and vulnerabilities across temporal and geographical scales (Louhisuo et al., 2007; Heltberg et al, 2008; Kaklauskas et al., 2009); the legal aspects of DRM and CCA; financing mechanisms at different scales; information on access to appropriate technologies and risk sharing and transfer mechanism for disaster risk reduction (see sections 7.4.1-7.4.4 above) are key to integrated risk management. 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 also vary across scale i.e. from the local level where participatory approaches are used to incorporate indigenous knowledge and build collective ownership of knowledge generated; to the broader regional to international levels thus upholding the principle of subsidiarity in the organisation, sharing and dissemination of information on disaster risk management (Marincioni, 2007; Chagutah, 2009).

An internationally agreed mechanism for acquisition, storage and retrieval and sharing of integrated climate change risk information, knowledge and experiences is yet to be established (Sobel and Leeson, 2007). Where this has been 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 DRR and CCA actors at different levels to use different options available for reducing climate risks. Such a mechanism will support efforts to mainstream CCA and DRR 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). 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 (Ogallo, 2010).

7.4.5.1. Knowledge Creation

Knowledge creation by its nature is a complex, continuous and non-linear and life-long process. Knowledge creation for DRR and CCA involves acquisition, documentation and evaluation of knowledge for its authenticity and applicability over time and beyond its point of origin (Rautela, 2005). Knowledge acquisition and documentation has to focus on the shifting in emphasis by HFA from reactive emergency relief to pro-active DRR to strengthen prevention, mitigation and preparedness and link with changes in CCA for instance from the traditional global view of climate change to the need for adaptation to focus on local scales (refer to 7.4.3.2 on Technologies for Extreme Events). This shift is rapidly extending to the public as shown by evidence that under a two year period, up to December 2010, a total of 480,984 chapters of the ISDR Global Assessment of Disaster Reduction Report had been downloaded (this is an aggregate figure for all chapters in all languages). 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 DRR approach (Köhler and Wächter, 2006).

There are huge efforts in DRR and CCA related knowledge acquisition, development and exchange by universities, government agencies, international organizations and to some extent the private sector but coordination of these efforts internationally is yet to be achieved (Marincioni, 2007). At the international level the international Council for Science (ICSU) is the main international body that facilitates and funds efforts to generate global environmental change (GEC) information that extends into DRR and CCA. ICSU a non-governmental organization with a global membership of national scientific bodies (121 members) and international scientific unions (30 members) that however maintain a strong focus on natural sciences (http://www.icsu.org/). However, there have been changes over the years and ICSU now works closely with the International Social Science Council (ISSC). There are four major global environmental change (GEC) research programmes facilitated by ICSU: DIVERSITAS, International Geosphere Biosphere Programme (IGBP), International Human Dimensions Programme (IHDP) closely tied to ISSC and the World Climate Research Programme (WCRP). These programmes have been supported by a capacity building and information dissemination wing; the System for Analysis, Research and Training (START). The four GEC programmes have had a significant role in generating the background science that forms the basis for CCA and DRR (Steffen et al., 2004). For CCA the link between science and policy is achieved through the IPCC process while for DRR it is through activities of ISDR.

However, there has been growing concern that GEC programmes are not integrated and provide fragmented information limited to certain disciplines. This concern led to the establishment of Earth System Science Partnership (ESSP) aiming to integrate natural and social sciences from regional to the global scale but it has failed to answer the growing need for integrated information (Leemans et al., 2009). As a result a major restructuring of the knowledge generation process both at the institutional and science level has been launched by ICSU and the main focus is on increased use of integrated approaches and co-production of knowledge with potential users to deliver regionally and locally relevant information to address environmental risks for sustainable development. These initiatives will influence the process of integration of DRR and CCA and their linkages to development in future (ISCU, 2010; Reid et al, 2010). An assessment of climate services for DRR and CCA is given in secion7.3.3.2 above. But the generation of climate change information has followed a top down approach relying on 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 (Schipper and Pelling, 2006; Weingart et al., 2000). 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 (Vera et al., 2010). 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 (Vogel and O'Brien, 2006) . In general locally relevant climate change risk information to effectively address CCA is lacking and the capacity to generate such information is inadequate a factor contributing to vulnerability (Weingart et al., 2000; Schipper and Pelling, 2006).

Knowledge acquisition and documentation requires capacity in terms of skilled manpower, infrastructure and appropriate institutions and funding (refer to 7.4.3.1 on Technology and Climate Change Adaptation). 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 have ceased to operate are not adequately equipped (Ogallo, 2010). 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 (Vogel and O'Brien, 2006; Carvalho, 2007).

Interdisciplinary generation of information i.e. bridging the traditional divide among the social, natural, behavioural, and engineering sciences continues to be a great intellectual challenge in climate change risk reduction. For e.g. despite the value of IT in DRR and CCA information retrieved through the Internet is rarely cross disciplines (Marincioni, 2007). The newly formed ISDR sponsored and ICSU promoted Integrated Research on Disaster Risk programme(IRDR) which aims at applying an integrated approach in understanding natural and human-induced environmental hazards will contribute towards building a comprehensive international knowledge bank on DRR and CCA (McBean, 2010).

7.4.5.2. Knowledge Organization, Sharing, and Dissemination

Exchange of disaster information worldwide has increased tremendously through for example, mass media and Information and Communication Technologies (ICT). The role of mass media in broader needs of DRR and CCA as opposed to disaster response is still limited although various regional initiatives such as the Network of Climate Journalists of the Greater Horn of Africa are being made to improve the situation (Ogallo, 2010). Clearly multiple strategies for disseminating and sharing knowledge and information are required for different needs at different scales (Glik, 2007; Maitland and Tapia 2007; Maibach et al., 2008; Saab et al., 2008; see also chapter 5 and 6). However, evidence of rapidly expanding public interest in DRR is that in under a two year period, up to , December 2010, a total of 480,984 chapters of the ISDR Global Assessment of Disaster Reduction Report had been downloaded - this is an aggregate figure for all chapters in all languages.

Disaster response and recovery are closely linked to provision of effective communication prior to and throughout the disaster situation (Paul, 2001; Zhang et al., 2002). 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 which may influence perception of risk and subsequent responses (Vasterman et al., 2005; Glik, 2007). 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 (Maibach et al., 2008; Chagutah, 2009; Kaklauskas et al., 2009).

Increased use of information communication technology (ICT) such as mobile phones, online blogging websites with interactive functions and links to other web pages and real time crowd-souring electronic commentary and other forms of web based social networked communications such as Twitter, Facebook etc. represent current tools for timely delivery of disaster information to people who need it, where such information is given in an appropriate format and language and facilitates to deliver the available information (Glik, 2007). There are emerging attempts to develop mobile phone based disaster response services for e.g. 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**).** Mobile Phones are now routinely used to disseminate disaster warning information within industrialised countries and the process is rapidly expanding to developing countries.

Information sharing and dissemination for disaster relief has improved through the established of ReliefWeb site (http://www.reliefweb.int) by UN OCHA in 1996. The ReliefWeb site so far offer the largest internet based international disaster information gathering, sharing and dissemination (Wolz and Park, 2006; Maitland and Tapia 2007; Saab et al., 2008). The International Charter (http://www.disasterscharter.org) provides space data that serves to augments the RelifWeb. But the UN OCHA ReleifWeb does not cover preparedness and disaster prevention to fully embrace CCA and DRR.

Despite the growing role of mass media and ICT in disaster response significant improvements are still needed to reduce disaster losses. The full potential of mobile phones and Internet facilities in disaster relief is yet to be exploited. The UN OCHA ReleifWeb poorly represents local to national level humanitarian activities for e.g. most of this information is not translated into different languages (Wolz and Park, 2006). 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). Other initiatives such as RAdio and InterNET (RANET), a satellite broadcast service that combines radio and internet to communicate hydro-meteorological and climate-related information are examples of an innovative measures being put in place to address the problem of limited access to internet in developing countries (Boulahya et al., 2005). 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 generally 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 and also the growing use of interactive web communication facilities provides for the filtering of tacit knowledge.

7.4.5.2.1. Disaster risk reduction and climate change adaptation

A great deal of knowledge dissemination is accomplished in academic institutions but this does not translate automatically to the general public. The use of information technologies (IT) such as computer networks, digital libraries, satellite communications, remote sensing, grid technology, Geographic Information Systems (GIS), for data and information integration for knowledge creation and exchange for growing to be important in integrating DRR and CCA (UN ISDR, 2005b; Louhisuo et al., 2007; see also 7.4.3.2 on Technologies for Extreme Events). IT offers interactive modes of learning which could be of value in distance education and online data sharing and retrieval. For 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 data on disasters in the world from 1900 to present. This data is useful for disaster preparedness, and vulnerability assessments (CRED, 2006). Another example is the DesInventar database in Latin America, developed in 1994 by the Network for Social Studies in Disaster Prevention (LA RED) is an inventory of small, medium and greater impact disasters (http://www.desinventar.net/) and aims to facilitates dialogue for risk management between actors, institutions, sectors, provincial and national governments. This initiative has been extended to the Caribbean, Asia and Africa by UNDP while UNFCCC provides a more local scale database on local coping strategies http://maindb.unfccc.int/public/adaptation> (UNFCCC, 2007).

IT capabilities in disaster risk reduction also lies in 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 (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). But this has not been transferred to other regions.

Other initiatives include the NetHope International that combines development and disaster issues into its IT-centric mandate (Saab et al. 2008). While RANET (http://www.oar.noaa.gov/spotlite/archive/spot_ranet.html) originally developed in Africa for drought and spread to Asia, Pacific, Central America and Caribbean has a strong community engagement and disseminates comprehensive information from global climate data banks combined with regional and local data and forecasts resulting in spin offs to food security, agriculture and health in rural areas (Boulahya et al., 2005). A network of extension agents, development practitioners and trained members of the community are used in RAINET to translate information into local context and languages and as a result RAINET is being considered for other educational initiatives such as the Spare Time University to improve access to learning in DRR with benefit on CCA (Glantz, 2007). RAINET has been found to reduce vulnerability to climate extremes in different areas in Africa but the main challenge is availability of technical support, follow-up training, power supply, and coordination (Boulahya et al., 2005).

From the Un ISDR, the emergence of the PreventionWeb (www.preventionweb.net/) facility, specifically to 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 and was built on the experience of Relief Web with the purpose of becoming a single entry point to the full range of global disaster risk reduction information and hence provides a common platform for institutions to connect, exchange experiences and share information on DRR, facilitating integration with CCA and the development process. 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. Hence while catering 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 but its full potential is yet to be realised and evaluated since it is still evolving.

In addition to the PreventionWeb with a DRR focus the number of web-based resource portals supporting both DRR and CCA have been increasing. These include among others, ProVention Consortium which had a DRR and climate focus (www.proventionconsortium.org/) but has now ceased to operate; Adaptation Learning Mechanism (www.adaptationlearning.net); Linking Climate Adaptation Network/CBA-X which has some DRR focus too (www.linkingclimateadaptation.org) and WeAdapt/WikiAdapt, an adaptation focus portal (www.weadapt.org). As a result most of these remain effectively used by their respective communities and have been noted to be poorly organised (Mitchell and Aalst, 2008). Performance of such IT information resources in disaster risk management could improve with more coordination and integration of CCA, DRR and development community.

7.4.5.2.2. Constraints in knowledge sharing and dissemination

Further all 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 even the most innovative tools like RANET show numerousmaintenance constraints particularly in remote areas (Boulahya et al., 2005).

There are differences in perception on the role of IT in the 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). Indications are that while there is increased circulation of disaster information this does not 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; UN 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; see also 7.4.3.2 on Technologies for Extreme Events). As a result the contribution of these relatively new facilities such as PreventionWeb will among others depend on accessibility and assimilation of IT in daily operations of institutions across the globe. Evidence show 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 (Glik, 2007; Lemos et al., 2007; Maibach et al., 2008; Chagutah, 2009).

A major constrain in climate change risk management results from the fact that communities working in disaster management, climate change and development operate separately even though they are all concerned with human wellbeing and this increases vulnerability to climate extremes leading to disasters (Schipper and Pelling, 2006; Lemos et al, 2007). 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 the use of insurance they fail to link this to climate risk reduction exposing communities to vulnerability to climate extremes. Similar observations have been made on cities where urban developers have no link with climate risk management community (Wamsler, 2006). But in fact both the development and climate adaptation communities are concerned with vulnerability to disasters. This could be a common point of focus facilitating collaboration in research, information sharing and practice as part of global security (Schipper and Pelling, 2006; Lemos et al., 2007).

Communication gaps between professional groups often results from different language styles and jargons. Heltberg et al, (2008) have 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. This has also been noted by others e.g. for better coordination among numerous humanitarian organizations (Saab etal., 2008) and in the FAO guide for disaster risk management (Baas et al., 2008; Also see Chapter 1). 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).

In conclusion literature shows that data and information on their own are not a complete solution to risk reduction. Resources to generate and supply information and experience in a usable form for each unique case so as to translate this to knowledge and action are a critical dimension in risk reduction. 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. Data gathering, information and knowledge acquisition and management for disaster relief has a longer history. The process of building integrated information resource tools that brings together experiences from CCA, DRR and development community are still being weakly formulated yet these hold the promise to reducing vulnerability to disasters in future.

7.5. Consideration for Future Policy and Research

How best can the experience with disaster risk reduction at the international level be used to help or strengthen climate change adaptation? The characteristics of the DRR regime (chiefly ISDR and the Hyogo Framework for Action, and the CCA regime (chiefly the UNFCCC and the IPCC) have been described in detail and assessed to the extent that the limited assessment literature allows. One clear conclusion is that the DRR world has much to learn from CCA and vice versa (IPCC 2009). It is widely proposed in the literature that disaster risk reduction and climate change adaptation should be “integrated”(Birkman and von Teichman 2010).

The call for integration of disaster risk reduction with climate change adaptation goes much further however (UN ISDR 2009a). It is argued that both disaster risk reduction and climate change adaptation remain outside the mainstream of development activities. The United Nations Global Assessment Report on Disaster Risk Reduction (GAR) calls for “an urgent paradigm shift” in disaster risk reduction to address the underlying risk drivers such as vulnerable rural livelihoods, poor urban governance, and declining ecosystems (UNISDR 2009a). The report also calls for the harmonization of existing institutional and governance arrangements for disaster risk reduction and climate change adaptation(p 181), and presents a 20-point plan to reduce risk (pp176-177).

These policy proposals come from an official UN report (UN ISDR 2009a), and they are widely supported in the scientific literature (O’Brien et. al. 2006, Schipper 2009) as well as in other government reports. (DFID 2005, German Committee for Disaster Reduction 2009, Commission on Climate change and Development 2009) as well as in the advocacy literature (Tearfund 2008).). More recently the widely reviewed ICSU (2010) report (called the Belmont Challenge) on Regional Environmental Change: Human Action and Adaptation that was commissioned by the major global environmental change research funders to assess international research capability required to respond to the challenge of delivering knowledge to support human action and adaptation to regional environmental change concluded by calling for a highly coordinated and collaborative research programme to deliver integrated knowledge required to identify and respond to hazards, risks and vulnerability, and develop mitigation and adaptation strategies. Similarly ICSU and the International Social Science Council (ISSC) carried out a wide consultative process to rethink the focus and framework of Earth system research. This consultation came out with four The Grand Challenges which require a balanced mix of disciplinary and interdisciplinary research to address critical issues at the intersection of Earth systems science and sustainable development (Reid et al, 2010):

- Improve the usefulness of forecasts of future environmental conditions and their consequences for people.
- Develop, enhance, and integrate observation systems to manage global and regional environmental change.
- Determine how to anticipate, avoid, and manage disruptive global environmental change.
- Determine institutional, economic, and behavioural changes to enable effective steps toward global sustainability.

Both the Belmont Challenge and the Grand Challenges are setting a international tone for an integrative approach to challenges such as DRR, CCA and development. There is no shortage of policy proposals designed to integrate disaster risk reduction and climate change adaptation for their common strengthening and benefit.

Official reports also list many reasons why more movement in this direction has been slowed to develop. One constraint is the difficulty of integration across scales, which is addressed in section 7.6 below. Two other sets of constraints are described as “the normative dimension” and “the knowledge dimension” (German Committee for Disaster Reduction 2009). The following challenges and constraints have been identified:

- Normative Dimensions (adapted from German Committee for Disaster Reduction 2009)
  - Absence of uniform methods, standards and procedures in vulnerability and capacity assessment and also in the design, formulation and implementation of adaptation plans, programmes and projects Lack of clear norms when applying vulnerability and capacity assessment and when designing and implementing adaptation measures.
  - The desire for stability and the tendency to rapidly restore normalcy limit the scope to explore and to take advantage of the opportunity after disaster and recover in an adaptive way by taking account of future climate change notion and desire for stability may hamper the chance to take advantage of change and dynamics – after disasters, the chance to use the opportunity and build back in an adaptive way considering future climate change is in most cases not taken – more commonly, infrastructure is rapidly built back to the pre-disaster condition.
  - The perception of climate risks as being a threat caused by external agents limits the level of acceptance of responsibility and awareness to act on adaptation.
  - Final objectives of education are the acquisition of knowledge as well as socialization. Thus capabilities are developed on a common denominator and the diversity of thinking is reduced, thus leaving little room for the creativity that is necessary for finding solutions to global problems such as DRR and CCA. Education systems in most countries focus on basic knowledge acquisition and socialization often limited to specific disciplinary focus, with little time or resources allocated towards creative problem solving. Such creative problem solving, and integrated thinking, is essential to addressing the complex socio-economic challenges of climate change (ICSU, 2010 and Reid et. al. 2010).
  - People’s exposure to hazardous areas in many countries is often caused by lack of enforcement of existing laws, standards or inappropriate land-use plans and the pursuit for quick economic returns. The revisions of existing standards and plans are constrained by the lack of awareness and norms for adaptation and attraction to temporal economic benefits at the expense of long-term consequences. In many countries zoning standards and laws, or lack of enforcement, lets people live and settle in hazardous areas provoking not only human suffering but also immense costs for the insurance companies – lack of norms for appropriate adaptation hinders the revision of existing standards.
  - The lack of standards and methods on general standards and norms of how to link DRR and CCA are often seen as potential barriers that for hinder the effective cooperation and development of indicators that could help towards improvement of vulnerability and capacity assessment as well as the methods for evaluation of adaptation policies, strategies and plans. and their success.
- Knowledge Challenges (adapted from German Committee for Disaster Reduction 2009)
  - Differences in the form of terminology used i.e. the different terms and definitions framed by both DRR and CCA communities. (DRR and CCA).

- Limited links between the different types of knowledge domain and work of both DRR and CCA communities (barrier for communication, joint programming and collaboration).
- Unavailability of information about the concrete effects of climate change at on the local level (see 7.4.5.1 on Knowledge Creation).
- Limited census based information on of relevant census data (social and economic parameters, particularly in the areas) especially in dynamic areas such as high fluctuations of people, economic instability etc.
- The existing workload limits does not allow for the familiarization with yet another cross-cutting issue to be mainstreamed into daily work.
- Lack of information on of the societal and political structures in the target area often leads to a failure in identifying and addressing the right stakeholders which eventually turns into unsuccessful and ineffective programs.
- Scientific knowledge on of climate change acquired by the scientific community has not translated or communicated trickled down to practitioners or it is communicated in a way that is hard to understand and derive practical knowledge of (see 7.4.5.2 subsection on Constraints in Knowledge Sharing and Dissemination).
- Donors practices and funding guidelines have not yet explicitly and extensively established linkages of adaptation with DRR. This has potentially discouraged the recipient organisations working on DRR not to include adaptation strategies into their proposals and vice versa.
- There exists a gap between theoretical knowledge about on mainstreaming and their applications. So far mainstreaming is not being put into practice.
- Lack of substantive knowledge and guidance in the treatment of how to deal with the aspect of uncertainty in climate change projections .
- Absence or lack of methods, standards and tools on how to mainstream CCA and DRR into other fields or potential sectors of development practice.
- Lack of appropriate indicators that could help in the process of effective for climate screening of ongoing projects and also in the formulation of climate smart/proofing of ongoing or future projects.
- Absence or lack of appropriate indicators for assessment that could measure successful adaptation and which could also be integrated incorporated into funding guidelines as well as monitoring and evaluation strategies (ICSU 2010).

This list of challenges and constraints (German Committee for Disaster Reduction 2009) is based upon an extensive literature survey and assessment and on interviews with a worldwide selection of 59 experts from all continents, the Pacific and Caribbean islands and covering a wide diversity of expertise. It gives rise a list of 36 recommendations many of which specify a need for research linking DRR and CCA.

For the purposes of this Special Report the question has been formulated in terms of what can be learned from the practice of DRR to advance CCA. It is clear from the literature however that cooperation between the DRR and CCA communities is a two way process. This has given rise to questions about how “integration” in practice at local and national levels might best be facilitated by change at the international level.

7.6. Integration Across Scales

7.6.1. The Status of Integration

The literature reflects three different perspectives on the integration of disaster risk reduction and climate change adaptation. One view common among the community of experts and practitioners is that climate change adaptation should be integrated into disaster risk reduction (Commission on Climate Change and Development, CCD, 2008a, b, c, Prabhakar et. al. 2009 p. 26). It has even been suggested that climate change adaptation is a case of “reinventing the wheel” (Mercer 2010) since disaster risk reduction covers much of the same ground and is “already well established within the international development community” (Lewis 1999, Wisner et. al. 2004). There is a sense of concern amongst the disaster risk reduction community about the much higher degree of political and public recognition that is given to climate change (Tearfund 2008), and a concern that funding for adaptation to climate change will be at the expense of disaster risk reduction (Mercer 2010). Practitioners in disaster risk reduction tend to have the view that climate change is one of a number of factors contributing to vulnerability and disasters, (Mercer 2010), and that therefore climate change adaptation needs to be taken on board. It has also been asserted that it would be politically expedient to draw upon this in accessing resources for disaster risk reduction both in terms of funding streams and political prominence (Mercer 2010).

A second view is adopted by many in the climate change adaptation community. They recognise a diversity of cross-cuttings risks that can be associated with the impacts of climate change and consider disaster risk reduction to be one of these (Birkmann and von Teichman 2010). They conclude that disaster risk reduction should be integrated into climate change adaptation.

A third and perhaps more widespread view is that both disaster risk reduction and climate change adaptation should be more effectively integrated into wider development planning (Glantz 1999, Lewis 2007, O'Brien et. al. 2006, Christoplos et al 2009, CCD 2009, UN ISDR 2009a).

At the practical level there are many steps already underway to bring about such forms of integration (See Chapters 5 and 6). The numerous hazards and disasters that are not directly linked to climate change but their impacts may serve to increase vulnerability to climate change. Nevertheless as noted above in Section 7.5 there are many obstacles to integration and it is by no means agreed that full integration between disaster risk reduction and climate change adaptation is possible, or desirable.

The potential benefits as well as the obstacles to integration can be examined in terms of three scales; the spatial, the temporal and the functional (Birkmann and von Teichman 2010).

7.6.2. Integration on a Spatial Scale

The literature reflects a view that DRR and CCA operate on different spatial scales (Birkmann and von Teichman 2010) and that therefore their integration in practice has been problematic or impracticable. Disasters are often thought of as events occurring at a specific location whereas climate change is thought of as a global or regional phenomenon. This view is now being modified as the need for locally based climate change adaptation becomes evident (Adger et. al 2005) as the impacts of local disasters are recognized as having more widespread impacts on a larger spatial scale (See Chapters 4 and 6and 7.2.1 above).

One commonly cited impediment to integration is that climate change projections do not provide precise information on a local scale (See chapter 3 above) and that adaptation strategies tend to be designed for entire countries or regions (German Adaptation Strategy to Climate Change 2008, Red Cross/red Crescent climate Centre 2007). There is also a difference in scale between the sources of disasters and climate change. There is a spatial mismatch between those countries that are primarily responsible for climate change and those that carry the burden of impacts resulting from, for example, more extreme weather events. This scale difference is associated with quite different views about international action for DRR than for CCA associated with global justice and security (Birkmann and von Teichman 2010).

7.6.3. Integration on a Temporal Scale

There is also a perceived difference in the temporal scales of CCA and DRR. The disaster community has traditionally been focussed on humanitarian response including relief and reconstruction in the relatively short term. (UN ISDR 2009b), whereas climate change and CCA have been recognized primarily as long-term processes with projections extending from decades to centuries (See Chapter 3 above) which poses problems to development communities usually with a shorter time span. More effective cooperation and integration between the DRR and the CCA practitioners could help to detect, address, and overcome these temporal scale challenges. This essentially requires the stronger recognition of the risks of climate related disasters in CCA and the incorporation of longer-term climate change risk factors into DRR.

7.6.4. Integration on a Functional Scale

The functional separation of CCA and DRR institutions, organizations and mechanisms extends across all three levels of management from local to national to international. At the international level there are weak links between the climate adaptation "regime" as expressed in the UNFCCC and the leading DRR "regime" in the form of the ISDR. The character of the two "regimes" is radically different, the former having the task of implementing an international agreement and the latter being a UN-wide interagency "strategy". The history of the evolution of the two institutional arrangements is markedly different. The disaster field has long been dominated by humanitarian and emergency response measures and has only relatively recently been moving towards a stronger mitigation or DRR approach. (Burton 2003). Similarly climate change was initially conceived as an atmospheric pollution issue and has slowly been repositioned as in the UNFCCC negotiations as also being a development issue. One consequence of the different evolution has been that the international climate regime (UNFCCC) is linked at the national level to environment ministries, whereas the disaster regime (ISDR) is linked to emergency planning and preparedness agencies or as in other cases to the office of President. Neither DRR nor CAA are well linked into economic planning and development agencies (UN ISDR 2009).

There is also a "top-down" versus "bottom-up" distinction (Hare et. al. 2012, Rayner 2010). Natural hazards and associated disasters have a long history, and DRR has moved slowly from local to national to international levels in response to the rationale described in Section 7.2 above. Climate change on the other hand came to attention as a result of the work of atmospheric scientists and was first recognized primarily as a global problem, and has subsequently moved down scale as the need for CCA became more apparent and pressing. This shows that the opportunity for the two exists in both, at the international level where DRR has progressed and at the national- and local level where CC is moving to.

7.6.5. Towards More Integration

An assumption of this Special Report is that CCA could be enhanced by learning from the experience of the DRR community. The literature shows a widespread view that the two could both benefit from closer integration with each other and that both would benefit society better if there was more integrated into development (UN ISDR 2009a). Integration across scales can be facilitated if integration between DRR and CCA were also to take place at local, national and international levels. Integration at the international level might help to facilitate integration at national and local levels although the opposite is also possible. This Special Reports is itself a prime example of emerging cooperation. It is in line with a wider evolution in the global environmental change science research community (whose products serve both DRR and CCA) led for example by ICSU on the need for integrated approaches (across various natural and social sciences and including co-production of knowledge with stakeholders) to environmental issues to be carried out under new institutional arrangements to provide relevant knowledge to policy makers for sustainable development. Whether closer cooperation in DRR and CCA could also lead to institutional change is a moot question, but it has been observed that the Hyogo Framework has been designed with a set of goals, activities and policy measures, for a 10 year period to end in 2015, (Tearfund 2008) and that the next major IPCC Assessment (the 5th Assessment) is due to be released in 2014. The proximate timing of these two events, falling hard on the heels of the Rio Plus 20 Conference in 2012 might provide opportunities for further moves towards cooperation between the DRR and the CCA communities.

Frequently Asked Questions (FAQs)

1) Why has climate change adaptation received more visibility at the international level than disaster risk reduction?

Climate change is a problem affecting the global public good of the whole atmosphere. All countries stand to be affected, whereas disasters are less "universal" in that they are perceived to affect nations mostly one at a time.

There is a stronger sense of collective global responsibility for climate change since the problem was created in the first place by the more developed countries. There has been a legal guarantee under the Climate Convention to provide funds for adaptation. No such undertaking has been made in the disaster risk reduction, and such funds that do become available have historically been used more for post-disaster emergency response than for anticipatory risk reduction.

2) Why is it difficult to implement DRR and CCA, and why do we continue to allocate many resources at the international level to disaster relief compared with DRR ?

The DRR and the Climate Change communities have evolved separately from different sectors or disciplines. Typically, many DRR practitioners come from emergency management, architecture, engineering, geographical studies etc., while a large proportion of CCA personnel come from the climate, meteorology and economics etc. Therefore the merging of programmes requires mutual education and committed teamwork between practitioners from diverse sectors. A further problem relates to the separate placement of DRR and CCA within different governmental structures, often described as freestanding 'silos'.

For example, disaster risk reduction may emerge from housing ministries, urban and international development and agriculture, while adaptation to climate change may be the province of departments of environment, energy or meteorology. The third reason relates to the reality that both DRR and CCA require sustainable solutions and this requirement inevitably presents a massive and long-term implementation challenge to all assisting groups.

Disaster relief consumes large international resources for varied reasons: first, the critical humanitarian need provides an urgent imperative that is impossible to ignore; second there is a continual escalation in the scale of disaster impact; third, the pressure of the global media creates an insistent demand for concerted and massive response, and fourth, the presence and pressure from the vast international NGO community and their supporters is fuelled by an outpouring of human compassion resulting in donations. Further disasters are considered to be short term while DRR and CAA are long term and hence better placed within the development goals of a country than relying on short term outside interventions as in a disaster.

3) Can disaster risk reduction and climate change adaptation be better harmonized at the international level, if so how?

Yes. Climate change and extreme events share inter-related causal mechanisms and vulnerability factors, and also significant overlap in terms of the international institutions, technical, and financial resources available to manage them. However, real efforts at harmonization have only occurred over the last five years or so, and CCA, DRM and poverty reduction are still considered to be poorly co-ordinated. Independent evaluations have shown that the main international agencies have made good progress in linking the issues in terms of defining policy goals, and awareness raising and advocacy. The main weaknesses, and therefore opportunities for improved harmonization in the future, are in inter-agency coordination, implementation, and sustained engagement at the national and local level.

4) Why should the international community become involved in insurance?

Losses from extreme weather often cross national borders and can be of such scale that local/national insurers cannot absorb them. If reinsurers fill this gap, then there is little need to involve international organizations or NGOs. However, the global reinsurance market can fail to provide the capital at a price necessary for local and national insurers to provide cover to the most vulnerable. Reinsurance premiums are typically significantly higher that the actuarial fair value (expected losses to the insurer), which means that premiums become ill affordable to low-income households and farmers. The World Bank, as an example, has responded to the high cost of commercial reinsurance by offering lower cost capital backups to public and private insurers, such as in Mongolia and Peru. The international community can provide other services to address market failure, such as building weather stations that are needed for index-based weather insurance. Finally, international organizations, such as the World Food Programme, may themselves want to insure their potential post-disaster liabilities.

5) What will happen with the availability and cost of insurance when combining the objectives of CCA and DRR?

CCA has added a new dimension to the provision of insurance to the most vulnerable. Because of mounting evidence that climate change may be influencing the frequency and severity of some types of weather extremes, there is increased interest on the part of international development and other organizations to provide security to the vulnerable. This strengthens the case for supporting insurance systems in the developing world, making them more available and affordable to the poor. There is also keen interest in both CCA and DRR communities to link insurance with disaster risk reduction, as evidenced by recent pilot programs, for example in Ethiopia, where farmers who contribute labour to reducing drought risks are compensated with lower insurance premiums.

6) How can the international frameworks become more adept/successful in reaching the local level directly and through national governments and regional organizations?

By their very nature, international frameworks tend to be broad-based. They are useful in establishing a shared global viewpoint on international issues. But in order for them to drill down to local levels, sometimes they have to be complemented by national and sub-national frameworks and actions that stay true to the spirit of international frameworks but are tailored to specific domestic and local circumstances.

7) Are existing institutions for deployment of financial resources adequate for managing current and future disaster risk?

There are an expending number of sources (windows) for financial assistance (grants and loans) and a growing number of implementing agencies, as well as the trend towards "direct access". The growth in funds is providing more opportunities to finance climate change adaptation. This is much less the case for DRR. At the same time the multiplicity of funds and sources makes access more complicated and creates bureaucratic impediments and coordination issues.

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Table 7-1: Estimated 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)

Chapter 8. Toward a Sustainable and Resilient Future

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Executive Summary

Adapting to climate extremes associated with rapid and severe climate change without transformational social change will be difficult: If not chosen through proactive policies, forced transformations and crises are likely to result. This chapter reviews the disaster risk management and climate change adaptation and development studies literature to describe knowledge on the risks of climate extremes for sustainable development and how society might face this challenge and so be made more resilient.

Current climate variability and projected changes in climate extremes pose different challenges to affected human and natural systems than those caused by changes in the means of climate variables. Where changes in extremes cause greater stresses on human and natural systems than changes in averages, direct impacts may be more unpredictable, and associated adaptation challenges are often greater. On the ground, the impacts of climate extremes are experienced alongside risks associated more directly with social, political and economic forces. Managing the impacts of extremes without taking multiple-stressors into account may lead to sub-optimal strategies and trade-offs; measures implemented to reduce one risk may end up enhancing others.

Building resilient and sustainable development pathways requires integrated, systemic approaches that enhance the capacity of social-ecological systems to cope with, adapt to, and shape unfolding processes of change, while taking into consideration multiple stressors, different prioritized values, and competing policy goals.. Evidence of the success and limitations of these approaches indicate that disaster risk management and adaptation policy can be reinforcing and supportive – but this requires careful coordination that reaches across domains of policy and practice.

Developing synergies between disaster risk reduction and adaptation to climate change requires a closer look at the values and interests that underpin development, including recognition of winners and losers, and implications for human security. Key challenges for both disaster risk reduction and climate change adaptation are to reassess and transform institutions and governance arrangements; create synergies across scales; and, increase access to information, technology, resources and capacity, particularly in countries and localities with the highest climate-related risks and weak capacities to manage those risks.

Interaction between climate change mitigation, adaptation and disaster risk reduction will have a major influence on the ways in which development transforms towards resilient and sustainable pathways. Trade-offs and synergies between the goals of mitigation and adaptation in particular will play out locally, but have global consequences in aggregate.

Generic approaches to disaster risk management and climate change adaptation, especially at the local scale, are likely to be less successful than ones tailored to the unique opportunities and challenges of the local context. Fostering flexible and sustainable livelihoods is one example of an important local and context-specific adaptation to climate change. Managing the risks associated with frequently occurring low-intensity events is one effective here-and-now strategy to adapt to climate change and build resilience to cope with future extremes. However, it is necessary to ensure that current risk reduction measures do not exacerbate current or future vulnerability, as choices made today can facilitate or constrain future responses. Even when ambitious risk reduction measures are implemented, there are often residual risks related to exceptional events.

Development planning and post-disaster recovery have often prioritized strategic economic sectors and infrastructure over livelihoods and well-being in poor or marginalized communities. This is partly a result of time-bound reconstruction funding and represents a missed opportunity for building local capacity and including local development visions in disaster risk reduction and climate change adaptation strategies. Technology transfer can help to reduce vulnerabilities to natural hazards and climate change, but needs to be accompanied by capacity development and anchored in local contexts.

Short-term and long-term perspectives on both disaster risk reduction and climate change adaptation are often difficult to reconcile. There are trade-offs between current decisions and long-term goals linked to diverse values, interests, priorities and visions for the future. Resilience thinking offers some tools for reconciling short-term and long-term responses, including integrating different types of knowledge, an emphasis on inclusive governance, and principles of adaptive management. Thresholds or tipping points exist in natural and socio-economic systems, and pose limits to resilience.

Addressing the underlying causes of vulnerability and the structural inequalities that create and sustain poverty and constrain access to resources can be considered a prerequisite for sustainability. This involves integrating disaster risk reduction in other social and economic policy problems, as well as a long-term commitment to managing risk.

Where vulnerability is high and adaptive capacity relatively low, it is likely that changes in extreme climate events and climate extremes will make it difficult for systems to adapt sustainably without transformational changes, as contrasted with incremental changes or business as usual. Such transformations, where they are required, represent significant challenges that call for increased emphasis on adaptive management, learning, innovation and leadership.

Iterative learning, which includes anticipation, cross-scale analysis and reflection, is a key component of sustainability in the context of climate extremes. However, few empirical results exist to demonstrate how to best facilitate and sustain such learning in practice. Developing new knowledge and innovation that supports transformation calls for adaptive leadership among a wide range of stakeholders; this includes questioning mindsets, assumptions and paradigms, and encouraging innovation and the generation of new patterns of response.

There is no single approach or development pathway conducive to living with climate change extremes. Choices and outcomes for adaptive actions to climate extremes and extreme events are complicated by divergent capacities and resources and multiple interacting processes. These are framed by trade-offs between competing prioritized values and objectives, and different visions of development that can change over time.

8.1. Introduction

This chapter focuses on the implications of climate change extremes and extreme events for development, and considers how disaster risk reduction and climate change adaptation together can contribute to a sustainable and resilient future. 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. Enhancing the capacity of social-ecological systems to cope with, adapt to, and shape change is central to building sustainable and resilient development pathways in the face of climatic change. Despite twenty years on the policy agenda, sustainable development remains contested, with well-defined tensions between understandings that emphasize its economic, social and environmental dimensions (Hopwood *et al*., 2005). Resilience refers to a systems concept and approach that examines how systems deal with and shape disturbance and surprise (Walker and Salt, 2006; Folke, 2006; Brand and Jax, 2007). Approaches that focus on resilience emphasize the need to manage for change, to see change as an intrinsic part of any system, social or otherwise, and to ‘expect the unexpected’. Resilience thinking contrasts with the conventional engineering systems emphasis on capacity to control and absorb external shocks in systems assumed to be stable, towards managing the capacity of evolving social-ecological systems to cope with, adapt to and shape change (Folke, 2006). Resilience approaches offer three key contributions for living with extremes: First in providing a holistic framework to evaluate hazards in coupled human-environment systems; second, in putting emphasis on the ability to deal with hazard or disturbance; and third, in helping to explore options to dealing with uncertainty and future changes (Berkes, 2007).

Extremes are translated into impacts by the underlying conditions of exposure and vulnerability associated with development contexts. For example, governance weaknesses often transform extreme events into disasters (Ahrens and Rudolph, 2006; Hewitt, 1997; Pelling, 2003; Wisner *et al*., 2004). At root, this is a discussion about decision-making and its framing for those at risk and engaged in risk management. 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 (UNDP, 2004; ISDR, 2009; World Bank, 2010a). 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.

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. Drawing on many of the key messages from earlier chapters, the objective is to assess scientific knowledge on the transformative changes needed, particularly in relation to development policies and pathways. The chapter recognizes that outcomes of changing extreme events depend on responses and approaches to disaster risk reduction and climate change adaptation, both of which 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. Yet there are different interpretations of development, different preferences and prioritized values and motivations, different visions for the future, and many trade-offs involved. Research on the resilience of social-ecological systems provides some lessons for addressing the gaps between these objectives. Transformative social, economic, and environmental changes can facilitate disaster risk reduction and adaptation (Kovats *et al*., 2005). A resilient and sustainable future is a choice that involves proactive measures that promote transformations, including adaptive management, learning, innovation, and build the leadership capacity to manage risks and uncertainty (Loorbach *et al*., 2008; Hedrén and Linnér, 2009; Pelling 2010a).

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 and climate change adaptation are concepts and practices that overlap considerably and are strongly complementary. Disaster risk reduction considers hazards other than those that are climate-related, such as earthquakes and volcanoes, while climate change adaptation considers vulnerabilities related to phenomena that would not normally be classified as discrete disasters, such as gradual changes in precipitation, temperature, or sea level. Examples of hazards that are addressed by both communities include flooding and droughts; and both are fundamentally rooted in localized, relatively bottom-up responses to vulnerabilities and impacts.

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. However, it requires modifying development policies, mechanisms, and tools, and identifying and responding to those who gain and lose from living with and creating risk. This is of 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 technologies can influence sustainable development. It also considers the trade-offs that are involved in decision-making.

8.2.1. Concepts of Adaptation, Disaster Risk Reduction, and Sustainable Development and How they are Related

Adaptation and disaster risk reduction are complementary and often overlapping approaches for reducing risks to sustainable development from disruptive climate extremes and extreme events. Although climate change adaptation also deals with slow changes in average climate conditions, it includes a disaster-risk-reduction component, since a significant fraction of climate change impact may consist of increased or modified disaster risks (IPCC, 2007). Because disaster risk reduction is based on risk assessments that will be affected by climate change, it can no longer be carried out without taking adaptation in account (Milly *et al*., 2008). Therefore although they are not identical concepts and practices, adaptation includes a disaster risk reduction component, and disaster risk reduction includes an adaptation component.

Adaptation to climate change has been defined as adjustments to reduce vulnerability or enhance resilience in response to observed or expected changes in climate, climate variability 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, based on perceptions of climate risk (Weber, 2010). Adaptation actions may be anticipatory or reactive and may be undertaken by public or private actors. In both principle and practice, adaptation is more than a set of discrete measures designed to address climate change; it is an ongoing process that encompasses responses to many factors, including evolving experiences with both vulnerabilities and vulnerability-reduction planning and actions (Tschakert and Dietrich, 2010; Wolf , 2011).

Adaptive capacity underlies action and is defined as "the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behavior and in resources and technologies." [IPCC WG II, AR4, chapter 17, p727]. Adaptive capacity can also be described as the capability for innovation and anticipation (Armitage, 2005), the ability to learn from mistakes (Adger, 2003), and the capacity to generate experience in dealing with change (Berkes *et al.*, 2003). Enhancing adaptive capacity under climate change entails paying attention to learning about past, present, and future climate threats, accumulated memory of adaptive strategies, and anticipatory action to prepare for surprises and discontinuities in the climate systems (Nelson *et al.*, 2007).

Adaptive capacity is uneven across and within sectors, regions, and countries (O'Brien *et al*., 2006). Although wealthy countries and regions have more resources to direct to adaptation, the availability of financial resources is only one factor determining adaptive capacity (Moss *et al*., 2010; Ford and Ford, 2011). Other factors include the ability to recognize the importance of the problem in the context of multiple stresses, to identify vulnerable sectors and communities, to translate scientific knowledge into action, and to implement projects and programs (Moser and Ekstrom, 2010). The capacity to adapt is in fact dynamic and influenced by economic and natural resources, social networks, entitlements, institutions and governance, human resources, and technology (IPCC Working Group 2, Summary for Policymakers, p.69). It is particularly important to understand that places with greater wealth are not necessarily less vulnerable to climate impacts and that a socio-economic system might be as vulnerable as its weakest link (Tol and Yohe, 2007; O'Brien *et al,* 2006). Therefore, even wealthy locations can be severely impacted by severe events, socially as well as economically, as the United States learned from Hurricane Katrina (IPCC WG 2, Chapter 7) and Europe from the 2003 heat wave (e.g., Salagnac, 2007). These risks may increase, given the possibility for novel hazards associated with climate change and extremes.

Current adaptation planning in many countries, regions, and localities is identifying a wide range of options, although the available knowledge of their costs, benefits, wider consequences, potentials, and limitations is limited (NRC, 2010). In many cases, the most attractive adaptation actions are those that offer development benefits in the relatively near term, as well as reductions of vulnerabilities in the longer term (Agrawala, 2005; Klein *et al*., 2007; McGray *et al*., 2007; Hallegatte, 2008a; NRC, 2010). An emerging literature discusses adaptation through the lens of sustainability, recognizing that not all adaptation responses are necessarily benign; there are tradeoffs, potentials for negative outcomes, competing interests, different types of knowledge, and winners and losers inherent in adaptation responses (Eriksen and O'Brien, 2007; Ulsrud *et al*., 2008; Barnett and O'Neill, 2010; Beckman, 2011; Brown, 2011; Eriksen *et al*., 2011; Gachathi and Eriksen, 2011; Owuor *et al*., 2011). Sustainable adaptation represents a shift in the boundaries of current approaches to adaptation, viewing it as a process that address the underlying causes of vulnerability and poverty, and a way of generating social transformation (Eriksen and O'Brien, 2007; Eriksen and Brown, 2011). Similarly, sustainable disaster risk reduction initiatives can be considered those that provide a useful, long-term function in everyday life as well as resources that can be used at times of extremes events, e.g., bridges that provide market access or public schools that can transform into evacuation sites or shelters during disasters (Pelling, 2010b; IFRC, 2002).

Disaster risk can be defined in many ways (see Chapter 1). In general, however, it is closely associated with the three interlinked concepts of hazards, exposure, and vulnerability. Hazards are usually interpreted as effects of physical phenomena such as floods, landslides, cyclones, drought or wildfires that are potentially dangerous to exposed populations or systems, although they can interact with other sources of stress as well. Purposeful harm (e.g., terrorist attacks) and technological accidents (e.g., chemical spills) or misuse also constitute hazards. 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 can be 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 can modify hazard patterns (MEA, 2005; Nicholls *et al*., 2008; Nobre *et al.* 1991; Nobre *et al*., 2005). Indeed, most weather-related hazards now have an anthropogenic element (Lavell, 1999, Cardona, 1996).

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). In the climate change community (IPCC, 2007), vulnerability is a more integrated concept, combining hazard, exposure, risk-management, and adaptive capacity (Füssel and Klein, 2006). Vulnerability can increase or decrease over time as a result of both environmental and socioeconomic changes (Blaikie *et al*., 1994; Leichenko and O'Brien, 2008). In general, improvements in a country's development indicators have been associated with reduced vulnerability (UNDP, 2004; Schumacher and Strobl, 2008). As countries develop, there is often a reduction in human mortality, yet an increase in economic loss and insurance claims (ISDR, 2009; Pielke *et al.* 2008; Economics of Climate Adaptation Working Group, 2009; World Bank, 2010b). However, some types of development may increase vulnerability or transfer it between social groups, particularly if development is unequal or degrades ecosystem services (Guojie, 2003). Even where growth is more equitable, vulnerabilities can be generated, for example when modern buildings are not constructed to prescribed safety standards (Hewitt, 1997; Satterthwaite, 2007).

Climate change can magnify many preexisting risks through changes in the frequency, severity and spatial distribution of weather-related hazards (Chapter 3), as well as through increases in vulnerability due to changing climate means (e.g., decreased water availability, decreased agricultural production and food availability, or increased heat stress) (Pouyaud and Jordan, 2001). Like adaptation, disaster risk reduction may be anticipatory (ensuring that new development does not increase risk) or corrective (reducing existing risk levels) (Lavell, 2009). Given expected increases in rural and urban populations in hazard prone areas, anticipatory disaster risk reduction is fundamental to reducing the risk associated with future climate extremes. At the same time, investments in corrective disaster risk reduction are required to address the accumulation of existing climate risks, for example those inherited from past urban planning or rural infrastructure decisions.

Sustainable development is an international goal that can be threatened in some areas by climate change extremes, thus climate change adaptation and disaster risk reduction are critical elements of long-term sustainability for economies, societies, and environments at all scales (Wilbanks and Kates, 2010). The generally accepted and most widespread definition of sustainable development 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). A number of principles of sustainable development have emerged, including the achievement of a standard of human well-being that meets human needs and provides opportunities for social and economic development; that sustains the life support systems of the planet; that broadens participation in development processes and decisions; and that accelerates the movement of knowledge into action in order to provide a wider range of options for resolving issues (WCED, 1987; NRC, 1999; Meadowcroft, 1997; Swart *et al.*, 2003; MEA, 2005). Because sustainable development means finding pathways that achieve both economic and environmental goals without sacrificing either, it is concept which is fundamentally political" (Wilbanks, 1994).

Discussions of relationships between sustainable development and climate change have increased over the past decades (Cohen *et al.*, 1998; Yohe *et al.*, 2007; Bizikova *et al.* 2010). Literatures on development and underdevelopment have considered how development paths relate to vulnerabilities to both climate change and to climate change policies (e.g., Davis, 2001; Garg *et al.*, 2009), as well as to other hazards. Clearly, some climate change-related environmental shifts are potentially threatening to sustainable development, especially if the trends or events are severe enough require significant adjustment of development paths, which have become unsustainable (e.g., the relocation of population or economic activities to less vulnerable areas). In such cases, both disaster risk reduction and climate change adaptation can be important--even essential--contributors to sustainable development.

In neither the case of disaster risk reduction or adaptation, however, has the record been encouraging to date in reducing vulnerabilities in practice, particularly in developing countries. The exception to this is the large number of lives saved over the last decade attributed to improved disaster early warning systems (IFRC, 2005). This success is instructive but there remains much more that can be done to reduce mortality and counteract growth in the number of people affected by disasters. For example, a recent self-assessment of progress by 102 countries against the objectives of the Hyogo Framework of Action (ISDR, 2009) indicates that few developing countries have conducted comprehensive, accurate and accessible risk assessments, which are a pre-requisite for both anticipatory and corrective disaster risk reduction. Likewise, there are limited examples to date of successful climate change adaptations, at least partly because the ability to attribute observed environmental stresses to climate change is still limited (Fankhauser *et al.*, 1999; Adger *et al.* 2007; Repetto, 2008). Both the adaptation and the disaster risk reduction perspectives have strengths to offer in responding to climate change extremes and extreme events, yet neither approach alone is sufficient as a long-term response to climate change.

If development affects vulnerability to disasters and climate change, the reverse is also true, since disasters can have significant impacts on poverty and economic growth. Econometrics analyses at national scale have reached different conclusions on the impact of disasters on growth. Albala-Bertrand (1993) and Skidmore and Toya (2002) suggest that natural disasters have a positive influence on long-term economic growth, probably due to both the stimulus effect of reconstruction and the productivity effect. Others, like Noy and Nualsri (2007), Noy (2009), Hochrainer (2009), Jaramillo (2009), and Raddatz (2009), suggest exactly the opposite, that the overall impact on growth is negative. As suggested by Cavallo and Noy (2010) and Loayza *et al.* (2009), this difference may arise from different impacts from small and large disasters, the latter having a negative impact on growth while the former enhance growth. At the local scale, Strobl (2011) investigates the impact of hurricane landfall on county-level economic growth in the United States. This analysis shows that a county that is struck by at least one hurricane in a year sees its economic growth reduced on average by 0.79 percentage point, and increased by only 0.22 percentage point the following year. Noy and Vu (2010) investigate the impact of disasters on economic growth at the province level in Vietnam, and found that lethal disasters decrease economic production while costly disasters increase short-term growth. Rodriguez-Oreggia *et al.* (2009) focus instead on poverty and the World Bank's Human Development Index at the municipality level in Mexico. They show that municipalities affected by disasters experienced an increase in poverty by 1.5 to 3.6 percentage point. Considering these important links between disasters and development, there is a need to consider disaster risk reduction, climate change adaptation and sustainable development in a consistent and integrated framework (Schipper and Pelling, 2006; O'Brien *et al.*, 2006).

8.2.2. The Role of Values and Perceptions in Shaping Response

Values and perceptions are important in influencing action on climate change extremes, as they can have significant implications for sustainable development. The disaster risk reduction community has used several points of view for resolving decisions about where to invest limited resources. These points of view include, for example, considerations of economic rationality and moral obligation (Sen, 2000). Value judgments are embedded in problem framing, solutions, development decisions, and evaluation of outcomes, thus it is important to make them explicit and visible. 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 but are also shaped by action, judgment, choice, attitude, evaluation, argument, exhortation, rationalization, and attribution of causality (Rokeach 1979), but values do not always clearly translate to particular behaviors (Leiserowitz *et al*., 2005). Adaptation and disaster risk reduction intervene in development processes, either by seeking to support the status quo or effect changes in development, and in doing so surface values. Recognizing and reconciling conflicting values increases the need for inclusiveness in decision-making and for finding ways to communicate across social and professional boundaries (Rosenberg, 2007; Vogel *et al*. 2007; Oswald Spring and Brauch, 2011).

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 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 elements of social capital, such as sense of place or of community, identity, or culture. This has long been observed within the disaster risk community (Hewitt, 1997; Mustafa, 2005) and in more recent work in the climate change community (O'Brien, 2009; Adger *et al*., 2010; Pelling, 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; Hedlund-de Witt, forthcoming). 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; Hunt and Taylor, 2009; Adger *et al*., 2010; O'Brien and Wolf, 2010), and are significant when considering the interaction of climate change and disaster risk, including the complexity of the temporal consequences of decisions (Pelling, 2003).

Two important frameworks have dominated attempts to establish priorities for risk management: human rights and economic approaches. Human rights approaches (Gardiner, 2010; Wisner, 2003) emphasize moral obligation to reduce avoidable risk and contain loss, and this 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 addressing 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 (Sphere, 2004). 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 UN Millennium Development Goals, 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 provides a range of frameworks for investment decisions built on cost-efficiency, and can help to reveal where calculated economic benefits are perceived to exceed costs as part of wider decision-making contexts. The calculated benefits of investing in risk reduction vary, but are often considered significant (see Ghesquiere *et al*., 2006; World Bank 2010). There are, however, extreme difficulties in accounting for the complexity of disaster costs and risk reduction investment benefits (Pelling *et al*., 2002). 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 *et al*., 2010; ISDR, 2002, 2009). At the same time, outcomes such as increased poverty and inequality (Fuente and Dercan, 2008), health effects (Murray and Lopez, 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. Other types of valuation emphasise institutional elements such as the 'moral economy' associated with the collective memory and identities of people living in non-western cultures in many parts of the world (Scott, 2003; Rist, 2000; Hughes, 2001; Trawick, 2001).

8.2.3. Planning for the Future

This section considers the tools that are available for helping decision-makers and planners think about and plan for the future in the context of climate change and extremes. Planning for a future with heightened uncertainty when the stakes are high, values disputed, and decisions urgent, creates tensions among different visions of development. Indeed, 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 (Miller, 2007). 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 storylines), that in early years can be compared with actual directions of change (Boulanger*et al.*, 2006a, 2006b).

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). The challenge for disaster risk reduction and climate change adaptation is to produce realistic regional and sub-national scenarios at longer timescales (see Gaffin *et al.*, 2004; Theobald, 2005; van Vuuren *et al.*, 2006, azerty2010; Bengtsson *et al.*, 2006; Grübler *et al.*, 2007; Hallegatte *et al.*, 2011a). Scenario development in the social sciences is often done in several stages. As a first step, structural projections of key 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 (e.g., Delphi exercises) may produce quantitative and qualitative scenarios, covering socioeconomic changes, scientific and technological developments, and changes in political mindsets, worldviews and cultural preferences. Because drivers of socio-economic change (e.g., demography, population preferences, technologies) and the behaviour of local climates are highly uncertain, scenarios must consider a wide range of possible futures (Lempert, 2007; Lempert and Collins, 2007; WGBU, 2008) to design adaptation strategies and analyze trade-offs (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 regrets strategies, flexibility and reversibility (e.g., Fankhauser *et al.*, 1999; Goodess *et al.*, 2007; Hallegatte, 2009).

With climate change, difficult choices may become increasingly necessary. In many locations, for example, adapting to reduced water availability may involve increased investments in water infrastructure to provide enough irrigation to maintain existing agriculture production, or a shift from current production to less water consuming crops (see ONERC, 2009; Rosenzweig *et al.*, 2004; Gao and Hu, 2011). The choices among different options depend on how the stakeholders see the region in coming 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 or adaptive management 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).

In contrast to predictive scenarios and risk management approaches, 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), and where poverty, inequity, and injustice is recognized by many as incompatible with a sustainable future (St. Clair, 2010; Redclift 1987, 1992). Pathways that require considerable transformation to reach sustainable futures of this kind can be supported by backcasting techniques. 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, can also open deliberative opportunities and inclusiveness in decision-framing and making. Where visioning is repeated it can also open possibilities for tracking transitional development and learning processes that make up adaptive strategy for risk management, based on surfacing the values and preferences of citizens (Robinson 2003).

Adding an anticipatory dimension to planning for the future is critical for striving towards transformational actions in the face of multiple and dynamic uncertainties. The literature on anticipatory action learning provides some experience on what this might look like (Kelleher, 2005; Stevenson, 2002). The framing and negotiation of decision-making and policy is made inclusive and reflexive through multiple rounds of stakeholder engagement to explore meanings of what different futures may involve, reflect upon unavoidable trade-offs and the winners and losers, and establish confidence to creatively adapt to new challenges (Inayatullah, 2006). This type of learning stresses the skills, knowledges, and visions of those at risk and aims to support leadership from even the most vulnerable..

Experiences in scenario building emphasize their usefulness for raising awareness on climate change (Gawith *et al.*, 2009). While much progress has been made by employing scenario building and narrative creation to explore uncertainties, surprises, extreme events, and tipping points, the transition from envisioning to planning, policy-making, and implementation remains poorly understood (Lempert, 2007). Similarly, more wide-spread uptake of even scientifically highly robust scenarios may be hampered by conflicting understandings of and practical approaches to uncertainty, differential scalar needs, and lack of training among users (Gawith *et al.*, 2009). Moreover, to move from framing public debates to policy-making and implementation, ultimately useful scenario building requires procedural stability, permanent yet flexible institutional and governance structures that build trust and experience to take advantage of new insights for effective and fair risk management (Volkery and Ribiero, 2009).

Changing core beliefs, including those on climate change, its causes and consequences, is a slow process (Volkery and Ribiero, 2009). This may be especially true for poor, marginalized, and vulnerable populations. Work in West and East Africa has shown that rural communities tend to underestimate external forces that shape their region while overestimating their own response capacity (Enfors *et al*., 2008; Tschakert *et al*., 2010). Misjudging external drivers may be explained by the low degree of control people feel they have over these drivers, resulting in reactions that range from powerlessness to denial. A combination of local- and global-scale scenarios that link storylines developed at several organizational levels (Biggs *et al*. 2007), personalizing narratives to create a sense of ownership (Frittaion *et al.*, 2010), and providing safe and repeated learning spaces (Kesby, 2005) can reduce such learning barriers.

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. 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, 2007). Combinations of disaster risk reduction and climate change adaptation, and synergies between the two, can contribute to a sustainable and resilient future, but this involves expanding the diversity of futures that are considered and identifying those that are desirable, as well as the short-term and long-term values and actions that are consistent with them (Lempert, 2007).

8.2.4. Technology Choices, Availability, and Access

This section describes the scope and framing effect of technology. Technology choices can contribute to both risk reduction and risk enhancement, relative to climate extremes and extreme events. The continuing transitions from one socio-technological state to another frame many aspects of responses to climate change risks. Assessments of roles of technology choices in responding to climate extremes are enmeshed in the wide range of technologies considered within a broad range of development contexts, where technology development and use are key to many development pathways. However, in nearly every case issues are raised about the balance between risk reduction and risk creation, including how limitations on access to emerging technologies can shape climate risks.

Technology choices can significantly increase risks and add to adaptation challenges (Jonkman *et al*., 2010), as in the case when modern energy systems and centralized communication systems are dependent on physical structures that can be vulnerable to storm damage. It has been 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). In some circumstances, technologies put in place to reduce short term risk and vulnerability can increase future vulnerability to extreme events or ongoing trends. For example, the use of irrigation has reduced farmer vulnerability to low and variable precipitation patterns. However, when the irrigation water is from a non-renewable source (e.g., the Ogallala-High Plains aquifer system of the U.S), the foreseeable reduction in future irrigation opportunities will mean an increase in vulnerability and the risk of increasing crop failures (AAG, 2003; Harrington, 2005).

In other cases, technologies are considered to be an important part of responses to climate extremes and disaster risk. This includes, for example, attention to physical infrastructure, including how to “harden” built infrastructures such as bridges or buildings, or natural systems such as hillsides or river channels, such 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, including 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 – although access to such technologies may be limited in some developing regions. Seasonal climate forecasts based on the results from numerical climate models have been developed in recent decades to provide multi-month forecasts, which can be used to prepare for floods and droughts (Stern and Easterling, 1999). Modern technological development is exploring a wide variety of innovative concepts that may eventually hold promise for risk reduction, for example through new food production technologies, although ecological, ethical and human health implications are often as yet unresolved (Altieri and Rosset, 2002).

Attention to technology alternatives and their benefits, costs, potentials, and limitations for both risk creation and risk reduction 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 term, it is possible to consider potentials for new technology development, given identified needs (Wilbanks, 2010). Nonetheless, in some circumstances technology put in place to reduce short-term risk and vulnerability can increase future vulnerability to extreme events or ongoing trends. For example, while large dams could mitigate drought and generate electricity, well known costs of social and ecological displacement may be unacceptable (Baghel and Nusser, 2010). Furthermore, unless dams are 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). In the Mekong region, dykes, dams, drains and diversions established for flood protection have unexpected consequences on risk over the longer term, because they influence risk-taking behavior (Lebel *et al*., 2009). In the United States, past building in floodplain areas downstream from dams that have now exceeded their design life has become a major concern; tens of thousands of dams are now considered as having high hazard potential (ASCE, 2010; FEMA, 2009; McCool, 2005).

Investments in physical infrastructure cast long shadows through time, because they tend to assume lifetimes of three to four decades or longer. The gradual modernization of a city’s housing stock, transport or water and sanitation infrastructure takes many decades without targeted planning. If they are maladaptive rather than adaptive, the consequences can be serious. This suggests a re-appraisal of technology that might promote more distributed solutions, for example multiple, smaller dams that can resolve local as well as more distant needs. This has been expressed in part of Thailand's Sufficiency Economy approach, where local development is judged against its contribution to local, national and international wealth generation (UNDP, 2007).

8.2.5. Tradeoffs in Decision-Making

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. The ethical implications of these trade-offs 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; Dalby 2009; Brauch, 2009a, 2009b).

There is no single or optimal way of adapting to climate change or managing risks. Often, trade-offs between short-term and long-term objectives are ambiguous. For example, focusing on and taking actions to protect against frequent events may lead to greater vulnerability to larger and rarer extreme events (Burby, 2006). This is a particular challenge for investing in fixed physical infrastructure. Social investments and risk awareness, including early warning systems, can be strengthened by more frequent low impact events that maintain risk visibility and allow preparedness for larger, less frequent events. In discussing trade-offs between addressing short-term and long-term risks context is important, and even in well-governed systems, political expediency will often distort the regulatory process in a way that favors the short term (Platt, 1999).

Trade-offs 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 many benefits accruing to private investors or governments through tax revenue. 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 against 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). This introduces the possibility for those benefiting financially to offset produced risk through risk reduction mechanisms ranging from fare wages and disaster resistant housing to enhance worker resilience to support for early-warning, preparedness and reconstruction. Such approaches have become mainstreamed in some businesses through corporate social responsibility agendas (Twigg, 2001), though these remain unusual.

Another example of trade-offs linked to climate change and development is the future need for risk reduction infrastructure that would require changes in ecologically or historically important areas. For example, when considering additional protection (e.g., dikes and seawalls) in historical centres, aesthetic and cultural elements as well as building costs will be taken into account. Existing planning and design standards to protect cultural heritage or ecological integrity may need to be balanced with the needs of adaptation (Hallegatte *et al.*, 2011a). Difficulties in attributing value to cultural and ecological assets mean that cost-benefit analyses are not the best tool to approach these type of problems. Multi-criteria decision-making tools (Birkmann, 2006) that incorporate a participatory element and can recognise the political, ethical, and philosophical aspects of such decisions can also be useful (Mercer *et al.*, 2008).

Disaster events surface additional needs for trade-offs. During disaster reconstruction, tensions frequently arise between demands for speed of delivery and sustainability of outcome. Response and reconstruction funds tend to be time limited, often requiring expenditure within 12 months or less from the point of disbursement. This pressure is compounded with multiple agencies working with often limited coordination. Time pressure and competition between agencies tends to promote centralised decision-making and the sub-contracting of purchasing and project management to non-local commercial actors. Both outcomes save time but miss opportunities to include local people in decision-making and learning from the event with the resulting reconstruction often failing to support local cultural and economic priorities (Berke *et al*., 1993; Pearce, 2003). At the same time 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. When successful, participatory reconstruction planning has been shown to build local capacity and leadership, bind communities and provide 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.

The impacts of climate change extremes across multiple scales also raises the issue of trade-offs. The challenge is to find ways to combine the strengths of multiple scales rather than having them work against each other (Wilbanks, 2007). Local scales offer potentials for bottom-up actions that assure participation, flexibility, and innovativeness. 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 (AAG, 2003). Larger 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 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? Many top-down interventions (from international donor development and disaster response and reconstruction funding to new adaption fund mechanisms and national programming) may unintentionally discourage local action by imposing bureaucratic conditions for access to financial and other resources (Christoplos *et al*., 2009). Top-down sustainability initiatives are often preoccupied with *input* metrics, 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 NRC, 2005).

To manage trade-offs and conflicts in an open, efficient and transparent way, institutional and legal arrangements are extremely important. The existing literature on legislation for adaptation at the state level is not comprehensive but those countries studied lack many of the institutional mechanisms and legal frameworks that are important for coordination at the state level (Richardson *et al*., 2009). This has been found to be the case for Vietnam, Laos and China (Lin, 2009). In the South Pacific, high exposure to climate change risk has yet to translate into legislative frameworks to support adaptation - with only Fiji, Papua New Guinea and Western Samoa formulating national climate change regulatory frameworks (Kwa, 2009). Where there is no national legislative structure, achieving local disaster reduction and climate change adaptation planning is very difficult. Still, where local leadership is determined, skilful planning is possible, even without legislation. This has been the experience of Ethekwini Municipality (the local government responsible for the city of Durban, South Africa) which has developed a Municipal Climate Protection Programme with a strong and early focus on adaptation without national level policy or legal frameworks to guide adaptation planning at the local level (Roberts, 2008, 2010).

One way around the challenges of trade-offs is to “bundle” multiple objectives through broader participation in strategy development and action planning, both to identify multiple objectives and to encourage attention to mutual co-benefits. In this sense both the pathway and outcomes of development planning have scope to shape future social capacity and disaster risk management. Policies and actions to achieve multiple objectives include stakeholder participation, participatory governance (IRGC, 2009), capacity-building, and adaptive organizations, including both private and public institutions where there is a considerable knowledge base reflecting both research and practice to use as a starting point (e.g., NRC, 2008).

8.3. Integration of Short-Term and Long-Term Responses to Extremes

When considering the linkages between disaster management, climate change adaptation and development, time-scales play an important role. Disaster management is increasingly emphasizing disaster risk reduction in addition to the more traditional emergency response and relief measures. This requires addressing underlying exposure and vulnerability issues in the context of hazards with 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).

Cross-scale (spatial and temporal) interactions between actions focusing on the short-term and those required for long-term adjustment can potentially contribute to both synergies and contradictions between disaster risk reduction and climate change adaptation. This section reviews the literature regarding synergies and trade-offs between short- and long-term adjustments. First, we review the implications of present day responses for future well-being. 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.

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 in the long-term. Positive implications can include increased resilience, capacity-building, broad social benefits from extensive participation in risk management and resilience planning, and the value of multi-hazard planning (see Chapter 5 and 6). Negative implications can 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 "levee effect," where the adaptive solution to a current risk management problem builds confidence that the problem has been solved, blinding populations to the possibility that conditions may change and make the present adaptation inadequate (Burby, 2006; Burby *et al*., 2006).

The terms coping and adaptation reflect strategies for adjustments to changing climatic and environmental conditions. In the case of a set of policy choices, both coping and adaptation denote forms of conduct that aim and indeed may achieve modifications in the ways in which society relates to nature and nature to society (Elsevier 2005). As discussed in Chapter 2, coping actions are those which take place in trying to alleviate the impacts or to 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 (Swift, 1989; Davies, 1993; Sperling *et al*., 2008). In developing countries, a focus on 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 (Bradley *et al*., 2006), sanitation, education and health care, require more immediate attention (Adly and Ahmed, 2009; Kameri-Mbote and Kindiki, 2009; Klein *et al*., 2005). Particularly, in poor rural contexts, short-term coping may be a trade-off that increases longer-term risks (ISDR, 2009; Brauch and Oswald, 2011). Adaptation, on the other hand, is often focused on minimizing potential risk to future losses (Oliver-Smith, 2007).

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 relocation of settlements to avoid coastal hazards undermines social capital and local livelihoods, limiting household coping and adaptive capacity (Hunter, 2005). There is a large literature and much experience related to slum relocation that is of direct relevance now to urban adaptation and coping (Gilbert and Ward, 1984; Davidson *et al*., 1993; Viratkapan and Perera, 2006).

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; López, 2009; van den Berg, 2010). The process by which a series of events generates 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 Santos, 2007; Alderman *et al.*, 2006; Bartlett, 2008).

Poverty traps at the micro level (i.e., the household level) may lead to macro-level poverty traps, such that entire regions are affected. Such poverty traps could be explained by an amplifying feedback: Poor regions have a limited capacity to rebuild after disasters, and if they are regularly affected by disasters, they do not have enough time to rebuild between two events, and they end up in a state of permanent reconstruction, with all resources devoted to repairs instead of new infrastructure and equipment; this obstacle to capital accumulation and infrastructure development leads to a permanent disaster-related under-development. This can even be amplified by other long-term mechanisms, such as changes in risk perception that reduce investments in the affected regions or reduced services that make qualified workers leave the region (see a discussion on the role of hurricane Betsy in triggering the decrease in New Orleans population). These effects have been discussed by Benson and Clay (2004), and investigated by Noy (2009) and Hochrainer (2009). They have been modeled by Hallegatte *et al.* (2007) and Hallegatte and Dumas (2008) using 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. There are, however, 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, 2009a, 2009b).

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, 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). 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 of future risk to climate extremes associated with increases in exposure, vulnerability and hazard.

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 due to a lack of governance capacity or technology. The recent national self-assessments of progress towards achieving the ISDR Hyogo Framework for Action indicated that some Least Developed Countries lack the human, institutional, technical and financial capacities to address even emergency management concerns (ISDR, 2009). The development deficit in many cities in developing countries, 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, through 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 under future conditions (Ranger *et al.*, 2011). Doing so, however, would require very large amounts of funding and careful governance especially where land titles are contested or some of the vulnerable might face relocation (Satterthwaite *et al.*, 2007, Bicknell *et al.*, 2009).

The World Bank, the UNDP and the UNFCCC estimated that the financial needs for adaptation will amount to between US$9 and US$166 billion per year, up to 2030. This is consistent 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). Even though the methodologies that have been used to calculate these estimates are questionable, the orders of magnitude are large enough to support the idea that funding will be a significant obstacle to adaptation in the future. The possibility that adaptation funding may be taken from development funding is counterproductive with development of basic and critical infrastructure being that basis upon which adaptation, and coping depend.

Another obstacle to reconciling short- and long-term goals is access to technology and maintenance of infrastructure. 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 (Metcalf and Eddy, 2005). Even in those regions where development has prioritized short-term gain over long-term resilience, agricultural productivity is in decline because of drought and groundwater depletion, rural indebtedness is increasing and households are sliding into poverty with particularly insidious consequences for women, who face the brunt of nutritional deprivation as a result (Moench et al., 2003; Moench and Dixit, 2007).

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 for example in a historical study of hurricane risk in the US (Birkland, 2007).

A change in the culture of public administration towards creative partnerships between national and local governments 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 (Pelling and Holloway, 2006). 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 Defence, 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).

In addition to the barriers described above, there is also tendency for individuals to focus on the short-run and to ignore low probability high impact events. Studies have identified a set of psychological and economic barriers shaping how people make decisions under uncertainty (Kunreuther *et al.* forthcoming). Some of the most important elements include:

Underestimation of the risk: Even when individuals are aware of the risks, they often underestimate the likelihood of the event occurring (Smith and McCarty, 2006). This bias can be amplified by natural variability (Pielke *et al.*, 2008), where there is expert disagreement, and where there is uncertainty. Magat *et al.* (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.

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 (Kunreuther *et al.* 1978:; Thaler, 1999).

Difficulties in Making Trade-offs: Individuals are also not skilled in making trade-offs 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: Individuals are observed to have deferred chosing between ambiguous choices (Tversky and Shafir 1992; Trope and Lieberman, 2003).

Samaritan's Dilemma: Anticipated availability of post-disaster support can undermine self-reliance when there are no incentives for risk reduction (Burby et al., 1991).

The Politician's Dilemma: Time delays between public investment in risk reduction and benefits when hazards are infrequent, and the political invisibility of successful risk reduction can be pressures for a NIMTOF (Not in My Term of Office) attitude that leads to inaction (Michel-Kerjan, 2008).

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. Examples of this challenge are reflected in the demographic growth of Florida in the 1970s and 1980s which unfolded during a period of low hurricane activity but now represents a significant population at risk, and major engineering projects with long lead-times from planning to implementation have difficulty factoring in climate change futures and have been planned on historic hazard risk (Pielke *et al.*, 2008). Managing natural risks and adapting to climate change requires anticipating how natural hazards will change over the next decades, but uncertainty on climate change and natural variability is a significant obstacle to such anticipation (Reeder *et al.*, 2009). 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, governments and businesses have been slow to invest in adaptation measures.

8.3.3. Connecting Short- and Long-Term Actions to Promote Resilience

The previous section highlighted the importance of linking short-term and long-term actions as disaster risk reduction and climate change adaptation come to support each other. 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 and disasters (Bahadur *et al.* 2010). It has developed as a fusion of ideas from several bodies of literature: ecosystem stability (e.g., Holling, 1973), engineering robust infrastructures (e.g., Tierney and Bruneau, 2007), psychology (e.g., Lee *et al.*, 2009), disaster risk reduction (e.g., Cutter *et al.*, 2008), vulnerabilities to hazards (Moser, 2009) 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. 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).

'Resilience thinking' (Walker and Salt, 2006) may provide a useful framework to understand the interactions between climate change and other challenges, and in reconciling and evaluating trade-offs between short-term and longer-term goals in devising response strategies. Resilience thinking contrasts with the conventional engineering systems emphasis on capacity to absorb external shocks. It 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). 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, and; the degree to which it can build capacity to learn and adapt (Folke, 2006).

Social-ecological systems have to deal with both gradual and abrupt changes (Folke, 2006). There are substantial uncertainties about how ecosystems will respond to increasing levels of human exploitation (Steffen *et al*. 2004), although most assessments agree it will likely increase the magnitude and frequency of large, abrupt, persistent changes in system structure and function, known as regime shifts (Steffen *et al*., 2004, MEA, 2005, Rockström *et al*., 2009). Gradual changes may erode system resilience to the point that even small disturbances may trigger large changes in social-ecological systems with significant social consequences (Adger, 2006) where vulnerability is high (Blaikie *et al*., 2004). 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 policy decisions. 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 considered bad: Folke (2006) emphasizes the capacity for renewal, re-organization and development in resilient social-ecological systems, whereby "disturbance has the potential to create opportunity for doing new things, for innovation and for development". This understanding of resilience embraces both the potential for development goals and practices to persist in the face of change and for innovation and transformation 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. Key to much resilience thinking is a focus on learning, innovation, and experimentation, with valid applications for climatic uncertainties and extreme events. Combining different types of knowledge, memory, the willingness to experiment, and flexibility for navigating complex feedbacks, non-linearities, thresholds, and system changes are all well recognized (Berkes *et al.*, 2003; Davidson-Hunt and Berkes, 2003; Folke, 2006).

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. However, Pielke *et al.* (2007) warn that locating adaptation policy in a narrow risk framework through concentrating only on identifiable anthropogenic risks can distort public policy because vulnerabilities are created through multiple stresses. Yet, 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). 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.

Recent work on resilience and governance has focused on the communication of science between actors and depth of inclusiveness in decision-making as key determinants of the character of resilience. In support of these approaches it is argued that inclusive governance facilitates better flexibility and provides additional benefit from the decentralisation of power. On the down side, greater participation can lead to lose institutional arrangements that may be captured and distorted by existing vested interests (Adger *et al.*, 2005; Plummer and Armitage, 2007). Still, the balance of argument (and existing centrality of institutional arrangements) call for a greater emphasis to be placed on the inclusion of local and lay voices and of diverse stakeholders in shaping agendas for resilience through adaptation and adaptive management (Nelson *et al.*, 2007). This is needed both to raise the political and policy profile of our current sustainability crisis and to search for fare and legitimate responses. Greater inclusiveness in decision making can help to add richness and value to governance systems in contrast to the current dominant approaches which tend to emphasize management control. When inevitable failures occur and disasters materialise less inclusive approaches risk public trust in science, undermine government legitimacy and public engagement in collective efforts to change practices and reduce future risk. Striking the right balance between command-and-control, which offers stability over the short term, but reduced long-term resilience is the core challenge that disaster risk management brings to climate change adaptation under conditions of climatic extremes and projected increases in disaster risk and impact.

Resilience thinking is not without its critiques (Nelson, 2009; Pelling, 2010). Shortcomings include the downplaying of human agency in systems approaches and difficulty in including analysis of power in explanations of change, which combine to effectively promote stability rather than flexibility, i.e., maintaining the *status quo* and thus serving particular interests rather than supporting adaptive management, social learning or inclusive decision-making. 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-term investing to 'hold-the-line' may diminish capital resources for other adaptations and hence reduced adaptive capacity to future sea level rise. Thus dealing with specific risks without a full accounting of the nature of system resilience can lead to responses that can potentially undermine long-term resilience. Despite an increasing emphasis on managing for resilience (Walker *et al.*, 2002; Lebel *et al.*, 2006), the resilience lens alone may not sufficiently illuminate how to enhance agency and move from the understanding of complex dynamics to transformational action.

8.4. Interactions among Disaster Risk Management, Adaptation to Climate Change Extremes, and Mitigation of Greenhouse Gas Emissions

In many instances, climate change adaptation and mitigation may be synergistic, such as land-use planning to reduce transport-related energy consumption and limit exposure to floods, or building codes 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 possibility of approaches that address both objectives simultaneously (IPCC, 2007, Wilbanks and Sathaye, 2007; Wilbanks, 2010; Hallegatte, 2009; Yohe and Leichenko, 2010; Bizikova *et al*., 2010). In this section we enlarge the scope of the interactions to include disaster risk reduction. The extent of adaptation required will depend on the mitigation efforts undertaken, and it is possible that these requirements could increase drastically as levels of climate change exceed systemic thresholds; whether in the geophysical system or in the socio-economic.

8.4.1. Adaptation, Mitigation, and Disaster Management Interactions

The extent to which future adaptation will be required is dependent on the extent and rapidity with which climate change mitigation actions may be taken and resulting risk unfolds for any given development context. This section reviews the ways in which mitigation and adaption interact with development in urban and rural contexts.

In an increasingly urbanised world, global sustainability in the context of a changing climate will depend on achieving sustainable and climate resilient cities. 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 (Newman and Kenworthy 1989; Bento *et al*., 2005; Handy *et al*., 2005; Grazi *et al*., 2008; Brownstone and Golob, 2009; Ewing and Rong, 2008; 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, 2010c; UN-HABITAT, 2009). Since urban forms influence both GHG emissions and climate vulnerability (McEvoy *et al*., 2006), urban planning may benefit from synergies (e.g., reduced car use may decrease GHG emissions and reduce air pollution in a way that enhance robustness to heat waves), but also face conflicts (e.g., expanding air conditioning to cope with heat waves may lead to higher GHG emissions if electricity is not decarbonized (Lindley *et al.*, 2006); a denser city may reduce GHG emission but increase heat wave vulnerability (Hamin et Gurran, 2009).

Disasters create opportunities to adopt more sustainable and risk-reducing technologies during reconstruction, including those that support mitigation. The 2005 Hurricane Katrina disaster in New Orleans, Louisiana, has been followed up with recovery efforts that include rebuilding to Green Building Council 'Leadership in Energy and Environmental Design' (LEED) standards (U.S. Green Building Council, 2010). 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 LEED Platinum standards (Harrington, 2010). Unfortunately, (echoing the trade-offs between speed and sustainability presented in 8.2.5) these actions have slowed rebuilding of the town, leading to loss in social capital while attempting to create a model 'green' community.

While urban sites offer opportunities for mitigation through diversified (household) production and energy conservation, rural areas are a focus for concentrated low or no-carbon energy production ranging from HEP to solar and wind farms, biofuel crops and carbon sink functions associated with forestry in particular and REDD+ projects. These investments can have significant local impacts on disaster risk through changes in land-use and land-cover that may influence hydrology or through economic effects and consequences for livelihoods. Some impacts can even go beyond local places. Recent impacts of biofuel production on rural livelihoods and global food security indicate the sensitivity of rural and urban systems, and the care required in transformations of this kind (Dufey, 2006; de Fraiture *et al.*, 2008).

8.4.2. Implications for Sustainable Development and Resilience

Reducing risk that takes mitigation into account is most likely to be sustainable if it considers social and ecological outcomes, as well as economic outcomes of development. Failure to do so could amplify the development failures that allow poverty and environmental problems to persist. This section examines trends in urban and rural development that interact with the goals of resilience and sustainable development.

Urbanization offers great opportunities, but these are seldom realized, especially by those most marginalized and vulnerable. More typically, urbanization compounds environmental problems. 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 (Birkmann, 2006). As cities grow they also modify their surrounding rural environment, and consequently generate a significant proportion of the hazard to which they are also 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 (Satterthwaite, 1997, UNDP, 2004). 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 (Mitchell, 1999; Pelling, 2003; 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 can reduce disaster risk, but it takes time to produce significant effects. It requires anticipation of future climate change, taking into account how climate will change over many decades and the uncertainty on this information. 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 (Gusdorf *et al*., 2008). 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 of adaptation and mitigation (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. There are also a growing numbers of large-scale slum/informal settlement upgrading programmes that aim to improve housing and living conditions for low-income households (Boonyabancha 2005; Satterthwaite 2010). Although the results for urban livelihoods, quality of life and sustainability have been mixed at best, these remain rare opportunities to insert adaptation and mitigation planning into urban strategic development.

Rural livelihoods and risk contexts are also being transformed by multiple pressures, including globalisation and changes in the scale of farming; contributing amongst less competitive smaller farms to a need for non-farm income; 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), and; access to remittances resulting from migration (either within or across national boundaries); (Chouvy and Laniel, 2007). 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). The implications of these transitions on local rural risk, and how far they may provide scope for mitigation has not been fully explored in the literature. Existing principles of coping can be applied, for example in arguing that diversification into non-agricultural livelihoods could enhance coping (Ellis, 1998; Marschke and Berkes, 2006).

The existence of multiple, intersecting stressors in rural and urban contexts draws attention to the importance of addressing the underlying drivers of risk as a means of both disaster risk management and adaptation, and of enabling mitigation.

8.4.3. Thresholds and Tipping Points as Limits to Resilience

Recent literature suggests that climate change could trigger large-scale, system-level regime shifts that could significantly alter climatic and socio-economic conditions (Lenton *et al*., 2008; Hallegatte *et al*., 2010, MEA, 2005). Examples of potential large-scale 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). At smaller scales, climate change is likely to exacerbate well-established examples of regime shifts, such as freshwater eutrophication (Carpenter, 2003), shifts to algae-dominated coral reefs (Hughes *et al*., 2003), and woody encroachment of savannas (Midgley and Bond, 2001). In combined social-ecological systems the exceeding of certain thresholds can also lead to large, dramatic changes (Scheffer *et al*., 2001; Scheffer, 2009). The abruptness and persistence of these changes, coupled with the fact that they tend to be difficult and sometimes impossible to reverse, means that they tend to have substantial impacts on human well-being. The notion of regime shifts therefore contrasts with traditional thinking about gradual change in a linear fashion by emphasizing the possibility of multiple self-organizing system states, threshold effects and nonlinear dynamics (Gunderson and Holling, 2002; Levin, 1998). The notion of regime shifts extends into the socio-economic realm, here tipping points are exemplified by profitability limits in economic activities (e.g., Schlenker and Roberts, 2006; OECD, 2007).

Observations and analysis of disaster events have also begun to identify tipping points for systems change. Disasters themselves are threshold-breaching events, where coping capacities of communities are overwhelmed (e.g. Blaikie *et al*., 1994; Sperling *et al*., 2008). Disasters may lead to secondary hazards, e.g., when the impacts from one disaster triggers others, as when hurricane impacts trigger landslides or when different disasters produce concatenated impacts over time. For example losses associated with droughts and firesduring the 1997/1998 ENSO event in Central America that increased landslide and flood hazard during Hurricane Mitch in 1998 (Villagrán, 2011). Critical social thresholds may be crossed as disaster impacts spread across society. For the poor, 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, 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 (Wisner, 2003).

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 research 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 compound 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.

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). Such non-linear change may lie beyond the capacity of adaptation to avoid serious disruptions. Examples include the disappearance of glaciers, effects of climate change on traditional livelihoods of indigenous cultures, 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), thresholds are likely to be reached earlier Responses to potential thresholds or tipping points range from efforts to establish monitoring systems to provide early warning of an impending system collapse (Scheffer *et al*., 2009; Biggs *et al*., 2009), to researching the balance of risks associated with geo-engineering to avoid such climate points (Kiehl, 2006; Virgoe, 2002).

8.5. Implications for Access to Resources, Equity, and Sustainable Development

The previous section assesses the interlinkages between adaptation, disaster risk reduction and mitigation objectives. This section takes the idea of interlinkages further by exploring the relationship between climate change adaptation, disaster risk management and mitigation, and larger issues related to equity, access to resources, environmental and ecosystem protection and related development processes, including the relationship between the current spatial distribution of disaster risk and underlying processes of unequal socio-territorial development and environmental injustices (Maskrey, 1994; Sacoby *et al*. 2010). Issues related to capacity and equity are discussed, including the idea that there will be winners and losers, and implications for enhancing human security and the achievement of other international goals.

8.5.1. Capacities and Resources: Availability and Limitations

The capacity to manage risks and adapt to changes are unevenly distributed within and across nations, regions, communities and households (Hewitt, 1983, Wisner *et al*., 2004, Beck, 2007). The literature on how these capacities contribute to disaster risk management and climate change adaptation emphasizes the role of economic, financial, social, cultural, human, and natural capital and with institutional context (Chapters 5-7). When the poor are impacted by disasters limited resources are quickly expended in coping actions that can further undermine household sustainability in the long-run, reducing capitals and increasing further rounds of hazard exposure or vulnerability. In these vicious cycles of decline households tend first to expend saving and then, if pressures continue, to withdraw members from non-productive activities such as school and finally sell productive assets. As households begin to collapse individuals may be forced to migrate or in some cases enter into dangerous livelihoods such as the sex industry. At each stage in this cascading series of actions household resources are lost and individuals exposed to greater levels of stress. This poverty and vulnerability trap means that recovery to pre-disaster levels of wellbeing becomes increasingly difficult (Chambers, 1989; Burton *et al*., 1993; Adger, 1996, Wisner *et al*., 2004).

Some demographic groups, such as children, children and the elderly 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 elderly are made additionally vulnerable to climate change related hazards by characteristics that also increase vulnerability to other social and environmental hazards (thus compounding overall vulnerability): deterioration of health, personal lifestyles, social isolation, poverty, and inadequate access to health and social infrastructures (OECD, 2006). These characteristics highlight well the ways in which social and environmental changes coevolve in the production of risk over time – in this case with changes in family structures and access to services in response to economic cycles, political and cultural trends evolving as the climate changes with potentially compounding effects.

_____ 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

The literature estimates that 66.5 million children are affected annually by disasters (Penrose and Takaki, 2006). Research on disaster impacts amongst children focuses on short- and long-term physical and psychological health impacts (Bunyavanich *et al*., 2003; Balaban, 2006; Bartlett 2008; del Ninno and Lindberg, 2005; Norris *et al.,* 2002; Waterson, 2006). Vulnerability to these impacts in part is due to the less developed physical and mental state of children, 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; Sánchez et al., 2010; 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, 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

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 disaster risk reduction or adaptation supported through child-centred programmes (Back *et al*., 2009; Tanner *et al*., 2009). 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; Back *et al.,* 2009; and 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).

_____ END BOX 8-1 HERE _____

Local knowledge (described variously in the literature as lay, traditional or indigenous knowledge) may reduce the risks of future hazard impacts. There is a long tradition of seeking to identify and bring such knowledges into planned disaster risk management in urban and rural contexts through participatory and community based disaster risk management (Pelling, 2007; Mercer *et al*., 2008; Bruner *et al*., 2001; Fearnside, 2001; Miles *et al*. 2004) and tools such as participatory GIS that explicitly seek to bring scientific and local knowledge together (Tran *et al*., 2009). Recent research on climate change has also identified the importance of culture, including traditional knowledge, in shaping strategies for adaptation (Heyd and Brooks, 2009; ISET, 2010).

Studies also show that gender matters, and 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 outcome is linked to unequal access to resources, land, public and privately provided services by women (Agarwal, 1991; Nemarundwe, 2003; Njuki *et al*., 2008; Thomas-Slayter *et al*., 1995). But women are also often the majority holders of social capital and the mainstay of social movements and local collective action providing important mechanisms for household and local risk reduction and potentially transformative resilience. Important here are local saving groups and microcredit/micro-finance groups some of which extend to micro-insurance. In a review of microfinance for disaster risk reduction and response in South Asia Chakrabarti and Bhatt (2006) identify numerous initiatives, including those that build on extensive social networks and connect to the formal financial services sector.

Both development planning and post-disaster recovery have tended to prioritise strategic economic sectors and infrastructure over local livelihoods and poor communities (Maskrey, 1989,1996). However, this represents a missed opportunity for building local capacity and including local visions for the future in planning the transition from reconstruction to development – opportunities which could increase long-term sustainability (Christoplos, 2006).

8.5.2. Sustainability of Ecosystem Services in the Context of Disaster Risk Reduction and Climate Change Adaptation

Reducing human pressures on ecosystems and managing natural resources more sustainably can facilitate efforts to mitigate the rate and magnitude of climate change and to reduce vulnerabilities to natural hazards and climatic extremes. The degradation of ecosystems is undermining their capacity to provide ecosystem goods and services upon which human livelihoods and societies depend (MEA, 2005; WWF, 2010), and to withstand disturbances, including climate change. There is evidence that the likelihood of regime shifts in socio-ecological systems may be increasing in response to the magnitude, frequency, and duration of climate change and other disturbance events (Folke *et al.,* 2004, MEA, 2005). Large, persistent shifts in ecosystem services not only affect the total level of welfare that people in a community can enjoy, they also impact the welfare distribution between people within and between generations and hence may give rise to new conflicts over resource use. They could result in domino effects of increased pressure on successive resource systems, as has been suggested in the case of depletion of successive fish stocks (Berkes *et al*., 2006). However, the thresholds at which ecosystems undergo regime shifts remain largely unknown, partly due to variability over space and time (Scheffer, 2009; Biggs *et al*., 2009).

Ecosystems can act as natural barriers against climate-related hazardous extremes, reducing disaster risk (Conde, 2001; Scholze *et al*., 2005). For example, mangrove forests are a highly effective natural flood control mechanism which will become increasingly important with sea level rise, and are already used as a coastal defense against extreme climatic and non-climatic events (Adger *et al*., 2005). The benefits of such ecosystem services are determined by ecosystem health, hazard characteristics, local geomorphology, and the geography and location of the system in respect to hazard (Lacambra and Zahedi, 2011). 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. In particular there is evidence that the loss of regulating services (e.g., flood regulation, regulation of soil erosion) erodes ecological resilience (MEA, 2005).

Ecosystems and ecosystem approaches can also facilitate adaptation to changing climatic conditions (Conde, 2001; Scholze *et al*. 2005). Conservation of water resources and wetlands that provide hydrological sustainability can further aid adaptation by reducing the pressures and impacts on human water supply, forest conservation for carbon sinks, and alternative sources of energy such as biofuels to reduce carbon emission have multiple benefits (Reid, 2006), as do coastal defenses and avalanche protection (Silvestri and Kershaw, 2010). Such changes in the constituents of an ecosystem can be used as levers to, enhance the resilience of coupled socio-ecological systems (Biggs *et al*., 2009).

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 and Zahedi, 2011, 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. Conservation of biodiversity and maintenance of ecosystem integrity may therefore be a key objective in improving the adaptive capacity of society to cope with climate change (Peterson *et al*., 1997; Elmqvist *et al*., 2003).

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 may 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).

The increasing international attention and support for efforts focused on Reducing Emissions from Deforestation and Degradation, maintaining/enhancing carbon stocks and promoting sustainable forest management (REDD+) is an example of where incentives for the protection and sustainable management of natural resources driven by mitigation concerns also has the potential of generating co-benefits for adaptation. By mediating run-off and reducing flood risk, protecting soil from water and wind erosion, providing climate regulation and providing migration corridors for species, ecosystem services supplied by forests can increase the resilience to some climatic changes. Locatelli and others (2010) recognize the conceptual linkages between mitigation and adaptation that forest conservation can provide. Primary forests tend to be more resilient to disturbance and environmental changes, such as climate change, than secondary forests and plantations (Thompson *et al*., 2009). However, forests are also vulnerable to climatic extremes, as recent experimental observations have shown (e.g. Nepstad *et al*., 2007) and modeling studies focused on examining the effects of global warming on forests ecosystems suggest (e.g., Vergara and Scholz, 2011). Hence, the role of forest ecosystems in climate change mitigation and adaptation will itself depend on the rate and magnitude of climate change and whether the crossing of ecological tipping points can be avoided.

8.5.3. Local, National, and International Winners and Losers

While climate-related hazards cannot always be prevented, the scale of loss and its social and geographical distribution does differ significantly, determined by the characteristics of those at risk and overarching structures of governance including the legacy of preceding development paths on social institutions, economy and physical assets (Oliver-Smith, 1994). But disasters also generate winners. These may be organisations or individuals who benefit economically from reconstruction, but also response (West and Lenze, 1994; Hallegatte, 2008b), through the supplying materials, equipment, and services – often at a premium price generated by local scarcity and inflationary pressures (Benson and Clay, 2004) or a result of poorly managed tendering processes (Klein, 2007). Areas not impacted by disaster can also experience economic benefits, for example in the Caribbean where hurricanes have caused international tourist flows to be redirected (Pelling and Uitto, 2001). Political actors can also benefit by demonstrating strong leadership post-disaster, at times even when past political decisions have contributed to generating disaster risk (Olson and Gawronski, 2003; Le Billon and Waizenegger, 2007; Gaillard *et al*., 2008). The same can be said for climate change, with very unequal consequences in various regions of the world and various economic sectors and social categories (O'Brien *et al*., 2004; Adger *et al*., 2003; Tol *et al*., 2004). Less directly, those who have benefitted from policies and processes, such as expansion of commercial agriculture or logging, can also be described as winners. However, costs and benefits are often separated geographically and temporally, making any efforts at distributional equity challenging. For example, in the case of Hurricane Mitch, which killed more than 10,000 people and caused as much as $8.5 billion in damages, deforestation and rapid urban growth are often cited among the key causes of the disaster related losses (Pielke *et al*. 2003; Alves, 2002).

Analyses of winners and losers associated with climate change and discrete hazards need differentiation. While individual events can be assessed as a snapshot of winners and losers, climate change as an ongoing process has no final state. Over time, it may produce different distributions of winners and losers, for example as areas experience positive and then negative consequences of changes in temperature or precipitation. Whether or not a particular place produces winners or losers from an extreme event or a combination of climate extremes and other driving forces also depends on perceptions. These may be shaped by the recovery process, but are strongly influenced by prioritized values (Quarentelli, 1984, 1995; O'Brien, 2009; O'Brien and Wolf, 2010).

In considering winners and losers from climatic hazards and extreme events, it also vital to recognize that the understanding of winners and losers is highly subjective, and depends upon an individual, group or society's dominant paradigms and perspectives. While some regard winners and losers as a natural and inevitable outcome of ecological changes and/or economic development, others suggest that winners and losers are deliberately generated by unequal political and social conditions (O'Brien and Leichenko, 2003). Lurking behind discourses about winners and losers are issues of liability and compensation for losses: i.e., if a population or an area experiences severe losses due to an extreme event (at least partly) attributed to climate change, whose fault is it? Issues of equity, justice, and compensation are thus increasingly being raised (O'Brien *et al*., 2010b), and it seems likely that efforts to assign responsibility will emerge as an issue for both governments and courts (Farber, 2007).

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 that can improve human security while also avoiding disasters. Human security addresses the combined but related challenges of upholding human rights, meeting basic human needs, and reducing social and environmental vulnerability (UNDP, 1994; Brauch, 2009a; Fuentes and Brauch 2009; Sen, 2003; Bogardi and Brauch, 2005; Brauch 2005a, 2005b). It also emphasizes equity, ethics, and reflexivity in decision-making and a critical questioning and contestation of the drivers of climate change (O'Brien *et al*., 2010b) and local impacts (Pelling 2010). Human security is realized through the capacity of individuals and communities to respond to threats to their environmental, social, and human rights (GECHS, 1999; Barnett *et al*., 2010). A number of studies have assessed the relationship between climate change and human 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*., 2010a). Among the most likely human security threats are impacts on health, food, water and soil (Oswald Spring, 2009a; Oswald Spring *et al*., 2011). 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 related to climate change are the possibilities of mass migration and/or violent conflict resulting from the biophysical or ecological disruptions associated with climate change (O'Brien *et al*., 2008). There are indications that migration conditions followed disasters in the distant past, as well as in current situations (see, e.g., Kinzig *et al*., 2006; Le Roy Ladurie, 1971; Peeples *et al*., 2006). 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 (Harrington *et al*., 2009; Scheffran, 2011), but also as a means of diversifying and increasing income. Disasters linked to extreme events often lead to forced displacement of people, as well as provoking voluntary migration amongst the less poor.

The relationship between climate risk and displacement is a complex one and there are numerous factors that affect migration (UNDP, 2009). Nonetheless, recent research suggests that adverse environmental impacts associated with climate change have the potential to trigger displacement of an increased number of people (Kolmannskog, 2008; Feng *et al*., 2010). Studies 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). The opportunities that population movement opens for risk reduction are seen in international remittance flows from richer to poorer countries. These are estimated to have exceeded US$318 billion in 2007 of which developing countries received US$240 billion (World Bank, 2008). More negatively, the social dislocation provoked by migration can lead to the breakdown of traditional rural institutions and associated coping mechanisms, for example, in the erosion of traditional community based water management committees in central and west Asia (Birkenholtz, 2008). Local coping and adaptive capacity can also be limited by increases in the number of female-headed households as men migrate (Oswald Spring, 1991; 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*., 2010; Brauch and Oswald Spring, 2011).

Despite the opportunities for disaster response and reconstruction to enhance development, 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 partial 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 society 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). Concerns range from increased needs for humanitarian assistance to concerns over environmental migration, emergent diseases for humans or in food chains, potentials for conflict between nations or localities over resources, and potential for political/governmental destabilization due to climate-related stresses in combination with other stresses, along with efforts to assign blame (Ahmed 2009; Brauch and Oswald Spring, 2011).

Adaptation planning that seeks long-term resilience is continually confronted by political instability 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 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). New interest in disaster and climate change as a security concern has brought in lessons from security policy on planning for relatively low-probability/high-consequence futures. Although during times of stress, it is easy for polities to drift towards militarization and authoritarianism for managing disaster risk (Albala-Bertrand, 1993), there are alternatives, such as inclusive governance, which 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 influences the success of international goals, particularly those linked to development. The AfDB and nine other development organizations (2003) highlighted in a qualitative assessment report that climate change may impact on progress towards Millennium Development Goals (MDGs) and in particular constrain progress beyond 2015, underlying the importance of managing climate risks within and across development sectors. DFID (2006) shows how each of the Millennium Development Goals is dependent on some aspect of disaster risk for success. Disaster impacts on the MDG targets are both direct and indirect. For example, MDG 1 (to eradicate extreme poverty and hunger) is impacted directly by damage to productive and reproductive assets of the poor and less poor (who may remain in poverty or slip into poverty as a result of disaster loss), and indirectly effected by negative macroeconomic impacts.

It is also important 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) can influence climate change adaptation.

The UN-ISDR *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters* (HFA) recognizes the climate variability and change are important contributors to disaster risk and includes strong support for better linking disaster management and climate change adaptation efforts (Sperling and Szekely, 2005). The HFA priorities for action have proven foresightfull in including resilience explicitly as a component. Priority Three calls for ‘Knowledge, innovation and education to build a culture of safety and resilience at all levels’. This provides a strong justification for international actors to invest in resilience building and one that does not require the addition of new international agreements to start work.

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

Considering the broad challenges described above, it is important to consider the fit of existing tools and the ways they are used, who uses them and how they interact and change-learn over time. Pursuing sustainable and resilient development pathways requires integrated and ambitious policy 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 consequences of, and responses to, climate extremes and disasters are local, but these responses need to be supported and enabled by actions at regional, national and global scales. This section first assesses the literature pertaining to tools and practices that can help address these issues, and then considers strategies to achieve transformational change. As the preceding sections in this chapter and other chapters in the report have argued, achieving a sustainable and resilient future requires a transformational change; and accomplishing such change will require a combination of adaptive management, learning, innovation, and leadership.

8.6.1. Approaches, Tools, and Integrating Practices

Examples of past experience for integrating resilience into sustainable development that can enhance adaptation to climate extremes include experience of both specific decision-support tools and the governance and institutional contexts in which these tools and subsequent decisions are made. Tools include those that enable s information gathering, monitoring, analysis and assessment, develop projections of possible futures, simulate threats and explore implications for response. Approaches need to combine understandings of potential stresses from climate extremes, along with possible tipping points for affected social and physical systems, with monitoring systems for tracking changes and identifying emerging threats in time for adaptive responses. This is challenging and requires methodologies that can be open to both quantitative and qualitative data and its analysis including participatory deliberation (NRC, 2010). Scenarios, narrative storylines (Tschakert and Dietrich, 2010) and simulations (Nichols *et al*., 2007) can help to project and facilitate discussion of possible futures. Institutional innovation aimed at improving the availability of risk information to decision makers includes the creation of national or regional institutions to manage and distribute risk information (Von Hesse *et al*., 2008; Corfee-Morlot *et al*., 2011) 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 beginning to offer ways of compiling information at different scales and from different institutions. A growing number of countries are also systematically recording disaster loss and impacts at the local level (DesInventar, 2010) and developing mechanisms to use such information to inform and guide public investment decisions (Comunidad Andina and GTZ, 2006; Comunidad Andina, 2009; Von Hesse *et al*., 2008) and for national planning. Unfortunately there is as yet only limited experience of the integrated deployment of such tools and institutional approaches, especially in ways that cross scales of risk management strategy development and decision-making. The following sections provide some more detail on current experience.

8.6.2.1. Modelling Tools

Various tools can be used to design environmental and climate policies. Among them, integrated environment-energy-economy models produce long-term projections taking into account demographic, technologic and economic trends (e.g., Edenhofer *et al*., 2006; Clark and Weyant, 2009). These models can be used to assess the consequences of various policies. However, most such models are at spatial and temporal scales that do not resolve specific climate extremes or disasters (Hallegatte *et al*., 2007). At smaller spatial scales, numerical models (e.g., input-output models, calculable general equilibrium models) can help to assess disaster consequences and, therefore, balance the cost of disaster risk reduction actions and their benefits (Gordon *et al*., 1998; Okuyama, 2004; Hallegatte, 2008b; Rose *et al*., 1997; Rose and Liao, 2005, 2007; Tsuchiya *et al*., 2007). In particular, they can compare the cost of dealing with disasters with the cost of preventing disasters. Since disasters have intangible consequences (e.g., loss of lives, ecosystem losses, cultural heritage losses, distributional consequences) that are difficult to measure in economic terms, the quantitative models are necessary but not sufficient to determine desirable policies and disaster risk reduction actions. Whether incorporated in models or used in other forms of analysis, cost-benefit analysis is useful to compare costs and benefits; but when intangibles play a large role and when no consensus can be reached on how to value these intangibles, other decision-making tools and approaches are needed. Multi criteria decision-making (Birkmann, 2006), robust decision-making (e.g., Lempert 2007; Lempert and Collins, 2007), transition management approaches (e.g. Loorbach, 2010; Kemp *et al*., 2007), and group-process analytic-deliberative approaches (Mercer *et al*., 2008) are examples of such alternative decision-making methodologies.

Also necessary are indicators to measure the successes and failures of policies. For example, climate change adaptation policies often target the enhancement of adaptive capacity. The effects and outcomes of policies are often measured using classical economic indicators like GDP. The limits of such indicators are well known, and have been summarized in several recent reports (e.g., CMEPSP, 2009; OECD, 2009). To measure progress toward resilient and sustainable future, one needs to include additional components, including measures of stocks, other capital types (natural capital, human capital, social capital), distribution issues, welfare factors (health, education, etc.). Many alternatives indicators have been proposed in the literature, but no consensus exists. Examples of these alternatives indicators include: the Human Development Index, the Genuine Progress Indicator, the Index of Sustainable

Economic Welfare, the Ecological Footprint, the normalized GDP (Jones, 2010; Costanza *et al*., 2004; Lawn, 2003; Costanza, 2000).

8.6.1.2. Institutional Approaches

Amongst the most successful disaster risk reduction and adaptation project are those that have facilitated the development of partnerships between local leaders and framing governmental or other extra-local stakeholders. This allows local strength and priorities to surface in risk management while acknowledging also that communities (including local government) have limited resource and strategic scope and alone can not always address the underlying drivers of risk. Local 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 (ISDR, 2009; Lavell, 2009; Reyos, 2010). 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 successes in disaster preparedness and response leading to drastic reduction in mortality due to tropical cyclones, built on solid local organization, have relied on sustained support from the national level (Ahmed *et al*., 1999; Bern *et al.,* 1993; Chowdhury, 2002; Elsner *et al*., 2008; Haque and Blair, 1992; Karim and Mimura, 2008; Knutson *et al*., 2010; Kossin *et al*., 2007; World Bank, 2010a). 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).

Risk transfer instruments, such as insurance, reinsurance, insurance pools, catastrophe bonds, micro insurance and other mechanisms, shift economic risk from one party to another and thus provide compensation in exchange for a payment, often a premium (ex post effect) (see 5.5.2.2, 6.3.3.3 and 7.4.5.1). Many obstacles to such schemes still exist particularly in low income and many middle income countries: including the absence of comprehensive risk assessments and required data, 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; Linnerooth-Bayer and Mechler, 2007). In addition, ex ante, these mechanisms can also help to anticipate and reduce (economic) risk as they reduce volatility and increase economic resilience at the household, national and regional levels (Linnerooth-Bayer, Mechler and Pflug, 2005). As one example, with such insurance, drought exposed farmers in Malawi have been able to access improved seeds for higher yielding and higher risk crops thus helping them to make a leap ahead in terms of generating higher incomes and the adoption of higher return technologies (Hazell and Hess, 2010; World Bank, 2005).

Risk reduction and adaptation can also be addressed through the enhancement of generic adaptive capacity alongside hazard-specific response strategies (IFRC, 2010). 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 generic foundations of resilient and sustainable societies (Pelling, 2010). 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).

8.6.2. Transformational Strategies and Actions for Achieving Multiple Objectives

The question of how to achieve transformations toward more sustainable and resilient development pathways is a key challenge for humanity in the decades ahead (Folke, 2006). Transformation can be defined as a fundamental qualitative change, or a change in composition or structure that is often associated with changes in perspectives or initial conditions. It involves a change in paradigm, including shifts in perception and meaning, changes in underlying norms and values, reconfiguration of social networks and patterns of interaction, changes in power structures, and the introduction of new institutional arrangements and regulatory frameworks (Folke *et al.*, 2010; Smith and Stirling, 2010; Pahl-Wostl, 2009; Folke *et al.*, 2009). Successful transformational strategies promote organisational arrangements that are capable of evolving over time as risk landscapes change.

Transformational change cannot be realized without understanding how and why change occurs, or does not occur. Traditional approaches to managing change successfully in businesses and organizations focus on defined steps to improve management of the problems at hand (Harvard Business School Essentials, 2003). Kotter (1996), for example, identifies an eight-step process for leading change: 1) create a sense of urgency; 2) pull together the guiding team; 3) develop the change vision and strategy; 4) communicate for understanding and buy in; 5) empower others to act; 6) produce short-term wins; 7) don't let up; and 8) create a new culture. Kotter (1996) also identifies eight errors that are often made when leading change, including, for example, allowing too much complacency, failing to create a sufficiently powerful guiding coalition, and underestimating the power of a sound vision (Kotter, 1995). It is also important to recognize that many change initiatives create uncertainty and disequilibria, and are considered disruptive or disorienting (Heifetz *et al.*, 2009). Consequently, fundamental change is often resisted by the people that it affects the most (Kotter, 1996, Kegan and Lahey, 2009). Helping people, groups and organizations to manage the resulting disequilibria is seen as essential to successful transformation.

Many of the recent approaches to change and transformation focus on learning organizations, and the importance of changing mindsets or mental models (Senge, 1990; Scharmer, 2009; Heifetz *et al.*, 2009). The "transformational change" literature distinguishes between technical problems that can be addressed through management based on existing organizational structures and cultural norms, and adaptive challenges that require a change in mindsets, including changes in assumptions, beliefs, priorities, and loyalties (Kegan and Lahey, 2009, Heifetz *et al.*, 2009). Treating disaster risk reduction and climate change adaptation as technical problems may focus attention on improving technologies, reforming institutions, or managing displaced populations, whereas viewing them as an adaptive challenge shifts attention towards gaps between values and behaviors (e.g., values that promote human security vs. policies or behaviors that undermine health and livelihoods), beliefs (e.g., a belief that disasters are inevitable or that adaptation will occur autonomously) and competing commitments (e.g., a commitment to maintaining aid dependency or preserving of social hierarchies). Although most problems have both technical and adaptive elements, treating an adaptive challenge only as a technical problem often results in failure (Heifetz *et al.*, 2009).

Transformative changes that move society towards the path of openness and adaptability depend not only on changes in mindsets, but also on changes in systems and structures. Case studies of social-ecological systems suggest that there are three phases involved in systems transformations. The first phase includes being prepared for, or preparing the system, for change. The second phase calls for navigating the transition by making use of a sudden crisis as an opportunity for change, whether the crisis is real or perceived. The third phase involves building resilience of the new system (Olsson *et al.*, 2004, Chapin *et al.*, 2010). Traditional management approaches emphasize the reduction of uncertainties, with the expectation that this will lead to systems that can be predicted and controlled. However, in the case of climate change, it is likely that significant uncertainties about future projections of climate variables and the statistics of climate extremes will remain. Consequently, there is a need for management approaches that are adaptive, and robust in the presence of large and irreducible uncertainties.

Both changes in management paradigms and the development of innovative methods are required to do justice to the complexity of social-ecological systems, which are 'complex adaptive systems' (Pahl-Wostl, 2007). The nature of transformative change can be captured by the concept of triple-loop learning (Argyris and Schön, 1978; Peschl, 2007). These three types of learning differentiate respectively among learning that improves efficiency, learning that reframes the goals that set conditions for practice, and learning that questions deep, underlying principles from which goals and behaviour are derived and legitimated (Pelling *et al.*, 2007; Birkmann *et al.*, 2008; Pahl-Wostl, 2009). Societal transformations can be described as multi-level and multi-loop processes, where triple loop learning allows for reexamining the underlying ideology and value systems. The example of flood management, which has been subjected to a global paradigm shift over the past decades, is used to illustrate the typical kinds of questions posed in the successive stages of learning (see Figure 8-1).

[INSERT FIGURE 8-1 HERE:
Figure 8-1: Sequence of learning loops in the concept of triple-loop learning applied to flood management (modified from Pahl-Wostl, 2009).]

Changes in systems and structures may call for new ways of thinking about social contracts, which describe the balance of rights and responsibilities between different parties. Social contracts that are suitable for technical problems can be limiting and insufficient for addressing adaptive challenges (Heifetz, 2010). 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, or catalyse transformative pathways building on pre-disaster trajectories. O'Brien *et al.* (2009) consider how resilience thinking can contribute to new debates about social contracts in a changing climate, drawing attention to trade-offs among social groups and ecosystems, and to the rights of and responsibilities towards distant others and future generations.

8.6.3. Facilitating Transformational Change

Adaptation that is transformative marks a shift from risk management's preference for finite projects with linear trajectories and readily identifiable, discrete strategies and outcomes (Schipper, 2007), towards an approach that includes adaptive management, learning, innovation and leadership, among other elements. These aspects of adjustment are increasingly seen as being embedded in ongoing socio-cultural and institutional learning processes. This can be observed in the many adaptation projects that emphasize learning about risks, evaluating response options, experimenting with and rectifying options, exchanging information, and making trade-offs based on public values using reversible and adjustable strategies (Leary *et al.*, 2008; McGray *et al.*, 2007; Hallegatte, 2009; Hallegatte *et al.*, 2011c).

8.6.3.1. Adaptive Management

In general terms, adaptive management can be defined as a structured process for improving management policies and practices by systemic learning from the outcomes of implemented strategies, and by taking into account changes in external factors in a proactive manner (Pahl-Wostl, 2007; Pahl-Wostl *et al.*, 2007). Principles of adaptive management can contribute to a more process-oriented approach to disaster risk management, and have already shown some success in promoting sustainable natural resource management under conditions of uncertainty (Medema *et al.*, 2008). Adaptive management is often associated with 'adaptive' organizations that are not locked into rigid agendas and practices, such that they can consider new information, new challenges, and new ways of operating (Berkhout *et al.*, 2006; Pelling *et al.*, 2007). Organizations that can monitor environmental, economic and social conditions and changes, respond to shifting policies 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 events. Those social systems that appear most adept at adapting are able to integrate formal organizational roles with cross-cutting informal social spaces for learning, experimentation, communication and for trust based and speedy disaster response (Pelling *et al.*, 2009).

Adaptive management is a challenge for those organisations that perceive reputational risk from experimentation and the knowledge that some local experiments are likely to fail (Fernandez-Gimenez *et al.*, 2008). Where this approach works best, outcomes have gone beyond specific management goals to include trust-building among stakeholders—a resource that is fundamental to any policy environment facing an uncertain future, which also has benefits for quality of life and market competitiveness (Pelling, 2010). It requires revisiting the relationship between the state and local actors concerning facilitation of innovation, particularly when experiments go wrong. Investing in experimentation and innovation necessarily requires some tolerance for projects that may not be productive, or at least not in the short term or under existing risk conditions. However, it is exactly the existence of this diversity of outcomes that makes societies fit to adapt once risk conditions change, particularly in unexpected and non-linear directions.

8.6.3.2. Learning

This dynamic notion of adaptation promotes learning as an iterative process in order to build resilience and enhance adaptive capacity now, rather than targeting adaptation in the distant future. Social and collective learning includes support for joint problem solving, power sharing, and iterative reflection (Berkes, 2009). The need to take into account the arrival of new information in the design of response strategies have been mentioned also for mitigation policies (Ha Duong *et al*., 1997; Ambrosi *et al*., 2003). Adaptive management is an incremental and iterative learning-by-doing process, whereby participants make sense of system changes, engage in actions, and finally reflect on changes and actions. Lessons from learning theories, including experiential learning (Kolb, 1984) and transformative learning (Mezirow, 1995), stress the importance of learning-by-doing in concrete learning cycles, problem-solving actions, and the re-interpretation of meanings and values associated with learning activities.

Learning as a key component for living with uncertainty and extreme events is nurtured by building the right kind of social/institutional space for learning and experimentation that allows for competing worldviews, knowledge systems, and values, and facilitates innovative and creative adaptation (Thomas and Twyman, 2005; Armitage *et al.*, 2008; Moser, 2009; Pettengell, 2010). It is equally important to acknowledge that abrupt and surprising changes may surpass existing skills and memory (Batterbury, 2008). Adaptation projects have demonstrated that fostering adaptive capacity and managing uncertainty on the go by adjusting as new information, techniques, or conditions emerge, especially among populations exposed to multiple risks and stressors, is more effective than more narrowly designed planning approaches that target a given impact and are dependent on particular future climate information (Pettengell, 2010; McGray *et al.*, 2007). In the humanitarian sector, institutionalized processes of learning have contributed to leadership innovation (see Box 8-2).

_____ START BOX 8-2 HERE _____

Box 8-2. Institutionalized Learning in the Humanitarian Sector

An important attribute of the humanitarian sector is its readiness to learn. Learning unfolds at multiple levels, including sector wide reviews of performance, practice (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, but they 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-doing experiments. Where experimentation may be more observable, for example in disaster prevention and risk reduction or reconstruction activities, there are significant gaps in documentation and impartial impact assessment that has slowed down the transferring of learning outcomes between organizations. Competition between agencies within the humanitarian and development sectors partly explain why there is more learning based on the sharing of experience inside organizations than across sectors. But the increasing scale and diversity of risk associated with climate change, and compounded by other development trends such as growing global inequality and urbanization, puts more pressure on donors to promote cross-sector communication of productive innovations and of the experimentation such innovation builds upon.

_____ END BOX 8-2 HERE _____

Action research and learning provides a powerful complement to resilience thinking, as it focuses explicitly on iterative or cyclical learning through reflection of success and failures in experimental action, transfer of knowledge between learning cycles, and the next learning loop that will lead to new types of action (Ramos, 2006; List, 2006). In this process, critical reflection is paramount; it also constitutes the key pillar of double loop learning, the questioning of what works and why that is fundamental to shifts in reasoning and behavior (Kolb and Fry, 1975; Argyyris and Schön, 1978; Keen *et al.*, 2005). Allowing time for reflection in this iterative learning process is important because it provides the necessary space to develop and test theories and strategies under ever changing conditions. It is through such learning processes that empowered agency can emerge and potentially be scaled up into everyday spaces to trigger transformation (Kesby, 2005).

8.6.3.3. Innovation

The transformation of society towards sustainability and resilience involves both social innovations and technological innovations, incremental as well as radical. In some cases, small adjustments in practices or technologies may represent useful steps towards sustainability, while in other cases there is a strong need for more radical transformations. Some of the literature on innovation focuses on ensuring economic competitiveness for firms in an increasingly globalized economy (Fløysand and Jakobsen, 2010), and some concentrates on the relationship between environment on the one hand and the competitiveness of firms on the other (Mol and Sonnenfield, 2000). In addition, there is a body of social science literature on innovation that has emerged during the last 15 years, motivated by the need for transforming society as a whole in more sustainable directions. Recent literature has brought out new ideas and frameworks for understanding and managing technology and innovation-driven transitions, such as the Multi Level Perspective (MLP) (Rip and Kemp, 1998; Geels, 2002; Geels and Schot, 2007; Markard and Truffer, 2008). Combining insights from evolutionary theory and sociology of technology, the MLP conceptualizes major transformative change as the product of inter-related processes occurring at the three levels of niches, regimes and landscape. The model emphasizes the incremental nature of innovation in socio-technical regimes. Transitions, i.e. shifts from one stable socio-technical regime to another—occur when regimes are destabilized through landscape pressures, which provide breakthrough opportunities for niche-innovations.

In this field of research there is a strong focus on systems innovation and transformation of socio-technical systems, with the potential of facilitating transitions from established systems for transport, energy supply, agriculture, housing, etc., to alternative, sustainable systems (Hoogma *et al*., 2002; Raven, 2010).Though not directly dependent on changes in technology, technological and social innovations are often closely interrelated, not the least in that they involve changes in social practices, institutions, cultural values, knowledge systems, and technologies (Rohracher, 2008). A central, basic insight established within this research is that social and technological change is an interactive process of co-development between technology and society (Kemp, 1994, Hoogma *et al*., 2002; Rohracher, 2008). Through history, new socio-technical systems have emerged and replaced old ones in so-called technological revolutions, and an important characteristic of such transitions are the interactions and conflicts between new, emerging systems and established and dominating socio-technical regimes, with strong actors defending business as usual (Kemp, 1994; Perez, 2002).

_____ START BOX 8-3 HERE _____

Box 8-3. Innovation and Transformation in Water Management

The impacts of climate change are predominantly linked to the water system, in particular through increased exposure to floods and droughts (Lehner *et al*., 2006; Smith and Barchiesi, 2009). Considering water as a key structuring element or guiding principle for landscape management and landuse planning requires technology, integrated systems thinking, and the art of thinking in terms of attractiveness and mutual influence, or even mutual consent, between different authorities, experts, interest groups, and the public. One of the most pronounced changes can be observed in the Netherlands where the government has requested a radical rethink of water management in general and flood management in particular. The resulting policy stream, initiated through the ‘Room for the River’ (*Ruimte voor de Rivier*) policy, has strongly influenced other areas of government policy. Greater emphasis is now given to the integration of water management and spatial planning with the regulating services provided by landscapes with natural flooding regimes being highly valued. This requires a revision of land use practices and reflects a gradual movement towards integrated landscape planning whereby water is recognized as a natural, structural element. The societal debate about the plans to build in deep-lying polders and other hydrologically unfavorable spots, and new ideas on floating cities indicate a considerable social engagement of both public and private parties with the issue of sustainable landscapes and water management. However, although such innovative ideas have been adopted in policy, they take time to implement, as there is considerable social resistance.

_____ END BOX 8-3 HERE _____

8.6.3.4. Leadership

Leadership can be critical for disaster risk reduction and climate change adaptation, particularly in initiating processes and sustaining them over time (Moser and Ekstrom, 2010). Change processes are shaped both by the action of individual champions (as well as by those resisting change) and their interactions with organisations, institutional structures and systems. Leadership can be a driver of change, providing direction and motivating others to follow, thus the promotion of leaders by institutions is considered an important component of adaptive capacity (Gupta *et al*., 2010).

Leaders who facilitate transformation have the capacity to understand and communicate a wide set of technical, social and political perspectives related to a particular issue or problem. They are also able to reframe meanings, overcome contradictions, synthesize information, and create new alliances that transform knowledge into action (Folke *et al*., 2009). Leadership also involves diagnosing the kinds of losses that people are likely to experience with transformation, such as the loss of status, wealth, security, loyalty, or competency, not to mention loved ones (Heifetz, 2010). Leaders helps individuals and groups to take action to mobilize “adaptive work” in their communities, such that they and others can thrive in a changing world by managing risk and creating alternative development pathways – or engaging and directing people during times of choice and change (Heifetz, 2010).

8.7. Synergies between Disaster Risk Reduction and Climate Change Adaptation for a Resilient and Sustainable Future

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 and under varying social and environmental conditions 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 et al. (2008) 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. Creating space and recognizing a diversity of voices often means reframing what counts as knowledge, engaging with uncertainties, nourishing the capacity for narrative imagination, and articulating agency and strategic adaptive responses in the face of already experienced changes and to anticipate and prepare for future disturbances and shocks (Tschakert and Dietrich, 2010).

Lessons learned in climate change adaptation and disaster risk reduction illustrate that managing uncertainty through adaptive management, anticipatory learning and innovation can lead to more flexible, dynamic, and efficient information flows, adaption plans, and transformational action. Engaging with possible and desirable futures and options for decision-making fosters knowledge generation that is essential for adaptive risk management as well as iterative change processes. Zooming in on uncertain elements and their likely impacts (e.g. changes in direction of rainfall and variability) and identifying factors that currently limit adaptive capacity (e.g. marginalization, lack of access to resources) allows for more robust decision-making that also integrates local contexts (asset portfolios, spreading and managing risks) with the climate context (current trends, likely futures, and uncertainties) to identify the most feasible, appropriate, and equitable response strategies, policies, and external interventions (Pettengell, 2010). Challenges remain with respect to anticipating low probability/high impacts events and potentially catastrophic tipping points. This is either because they represent futures too undesirable to imagine, especially under circumstances where exposure and vulnerability are high and adaptive capacity low, or because they are perceived as inconsistencies or logically impossible (Volkery and Ribiero, 2009). Moreover, anticipating vulnerabilities as well as feasible and fair actions may also reveal limits of adaptation and risk management, and thus the potential need for transformation. Yet, decisions about when and where to facilitate transformative change and to whose benefit are inherently normative and cannot be approached without understanding related ethical and governance dimensions.

There are, however, 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 (IFRC, 2010). 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).

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 among social groups may hinder learning), or within nations (where marginalized groups may not be heard, and where social division and political power influence the development and adaptation agenda). These periods are frequently the times when those most affected are not consulted on their development visions and aspirations for the future. Instead, international social movements and humanitarian NGOs, government agencies and local relief organisations are likely 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 political or economic interests. The distribution of power in society and who has the responsibility or right to shape the future through decision-making today is thus significant.

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 experiment and accept the possibility of failure in processes of learning and innovation, transparency of values, and active engagement of civil society. Committing to such a learning process is, as Tschakert and Dietrich (2010, p. 17) argue, preferable to alternatives because "Learning by shock is neither an empowering nor an ethically defensible pathway."

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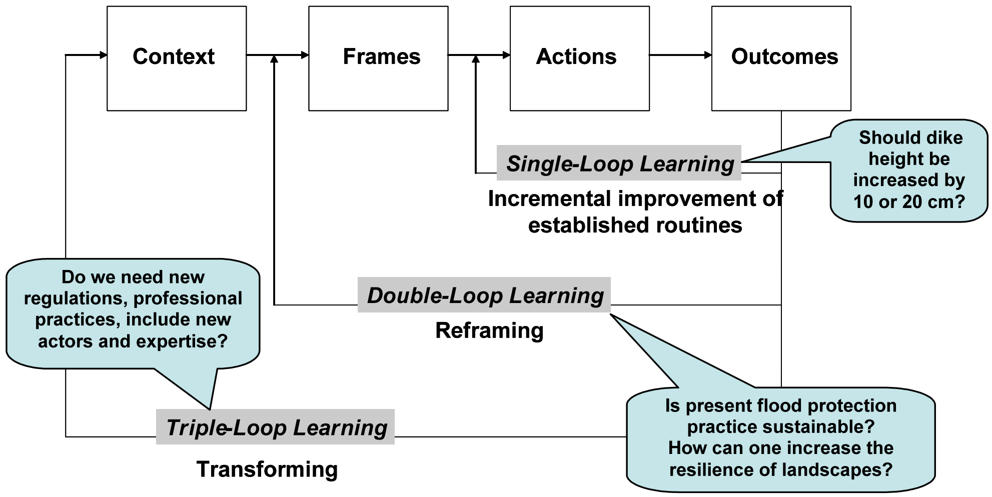

Figure 8-1: Sequence of learning loops in the concept of triple-loop learning applied to flood management (modified from Pahl-Wostl, 2009).

Chapter 9. Case Studies

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Contents

9.1 Introduction

In this chapter, case studies are used as examples of how to gain a better understanding of the threats posed by extreme climate-related events while identifying lessons and best practices from past responses to such occurrences. The case studies were chosen to be illustrative of a range of extreme events while also considering some generally vulnerable areas as well as methodological approaches. The case studies examining specific extreme events are: urban heat waves; droughts and associated dust storms; cyclones; and floods. Hazards often occur in complex combinations and these are demonstrated through examples of: complex hot situations with heat and wildfire; complex cold impacts in Mongolia and the Canadian Arctic; and health risks using cholera as the example. As Chapter 3 has projected that many extreme climate events will increase in frequency and/or magnitude in many regions of the world, there is need for early warning systems which are a common adaptation approach to reduce loss. A case study on cities and less-developed small-island states illustrates specific examples of vulnerability. Risk transfer, legislation and governance and education are presented as examples of methodological ways of climate change adaptation and disaster risk reduction. This selection provides a good basis of information and served as an indicator of the resources needed for future disaster risk reduction. Additionally, it allows good practices to be determined and lessons to be extracted. The case studies provide the opportunity for connecting common elements across the other chapters.

Case studies are widely used in many disciplines including health care (Keen and Packwood, 1995; McWhinney, 2001) social science (Flyjberg, 2004), engineering, and education (Verschuren, 2003). 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 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 and it is important that there be a good theoretical basis arising from application of rigorous methodology and comparative multi-case logic (Eisenhardt, 1989). From the work of Grynszpan *et al.* (2011) it is apparent that:

- Case studies capture the complexity of disaster risk and disaster situations;
- Case studies appeal to a broad audience; and
- Disaster reduction needs to make the most of each single case.

The case studies included in Chapter 9 have been prepared from a variety of literature sources prepared in many disciplines. As a result an integrated approach that examines scientific, social, economic and political aspects of disasters and includes different spatial and temporal scales is needed. The specialized insights they provide are invaluable in evaluating some current disaster response practices.

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 through the indirect impact of, for example, the reduction of food production in the region or a decrease in available resources. In addition to the spatial scales, this chapter also addresses temporal scales which vary widely in both event-related impacts and responses. 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). Developing countries with less resilient resources, experts, equipment and infrastructure have been shown to be particularly at risk (Chapter 5). Developed nations are usually better equipped with technical, financial and institutional support to enable better adaptive planning including preventative measures and/or quick and effective responses (Gagnon-Lebrun and Agrawala, 2006) . However they still remain at risk of high impact events as exemplified by the European heatwave of 2003 and Hurricane Katrina (Parry *et al*., 2007).

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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9.2. Cases Studies

Case Study 9.2.1. Cyclones: Enabling Policies and Responsive Institutions for Community Action

<u>Introduction</u>

Tropical cyclones, also called typhoons and hurricanes, are powerful storms generated over tropical and sub-tropical waters. Their impacts include extremely strong winds damaging buildings and infrastructure, torrential rains causing floods and landslides, and high waves and storm surge leading to extensive coastal flooding. An example of the destructive power of a seemingly unremarkable cyclone was the devastation caused by Typhoon Morakot in Taiwan (Lin et al. 2011). On 7 August 2009, Typhoon Morakot, which was classified only as a category 1 cyclone (maximum wind speed was less than 32.6 m/s), made landfall on the east coast of Taiwan. Other than its movement being about 30% slower than an average typhoon and a relatively large wind field radius of about 400 km, Morakot did not show any obvious extraordinary characteristics. However, Morakot set the record for the highest one-day precipitation, continuous two-day precipitation and total accumulation over the duration of a typhoon (3060 mm, from 6 to 10 August 2009) in Taiwan (Lin et al. 2011). The record amount of precipitation caused the worst flooding in Taiwan since 1959 and triggered over 50,000 landslides that seriously damaged nearly all roads in the central and southern mountains of Taiwan. Close to 700 people lost their lives, including 400 inhabitants of a village that was buried by a landslide. Total damages to property and infrastructure, and agricultural losses were estimated to be about US$ 3 billion.

The uncertainties in the historical tropical cyclone records, the incomplete understanding of the physical mechanisms linking tropical cyclone metrics to climate change, and the degree of tropical cyclone variability provide only low confidence for the attribution of any detectable changes in tropical cyclone activity to anthropogenic influences. However, there is medium confidence that the frequency of the most intense storms will increase in some ocean basins and it is likely that tropical cyclone-related rainfall rates will increase with greenhouse warming (see Chapter 3).

Various issues related to the risk management practices and changing temporal and spatial vulnerability of the population exposed to tropical cyclones are discussed in this case study. In particular, the comparative studies clearly demonstrate that efforts towards disaster risk reduction can be effective in the context of adaptation to extreme tropical cyclone events.

<u>Government Policies – Learning from Past Disasters</u>

Dealing with the Tropical Cyclone Risk in Bangladesh

Bangladesh experiences on average a severe tropical cyclone (wind speed 90-120 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 has been considerably reduced with each succeeding event as shown in the Table 9-1.

[INSERT TABLE 9-1 HERE:
Table 9-1: Affected people and fatalities caused by tropical cyclones Bhola (1970), Gorky (1991), and Sidr (2007) in Bangladesh.]

The 1970 Bhola cyclone was 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 greater number of people than Bhola, the loss of life for those events was dramatically reduced compared to Bhola.

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 taken by the Government in partnership with donors, NGOs, humanitarian organizations and, most importantly, by involving the vulnerable coastal communities themselves.

First, the construction of cyclone shelters in the coastal regions has provided safe refuge for coastal populations. These shelters are multi-storied buildings with capacity for 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 to be 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). These volunteers helped to evacuate around 350,000 people to cyclone shelters during Gorky in 1991 and, with a sevenfold increase of cyclone shelters and twofold increase of volunteers; 1.5 million people were 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 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. The key improvements in the above three measures for reducing disaster risks from tropical cyclones in Bangladesh are listed in Table 9-2.

[INSERT TABLE 9-2 HERE:
Table 9-2. Improvements in key measures for reducing risk of tropical cyclones in Bangladesh since 1970.]

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 world's largest mangrove forest, the Sundarbans, lies along the south-western coast of Bangladesh, providing a spatial buffer for population and crops and reducing storm surges energy. Cyclones Bhola and Gorky had landfall in the middle and eastern coast with little or no forest. On the contrary, Sidr had landfall in western coast covered by the Sundarbans, which cushioned and reduced the impacts considerably (Paul 2009). 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).

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). Over 1,500 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 occurred in islands where cyclone shelters were non-existent or inadequate in numbers or not in usable condition (GoB 2008). In contrast, 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 recognized as an effective way to promote local development as well as to ensure regular maintenance for their effective use during cyclone emergency (Chowdhury 2002).

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 tropical cyclone events and sea level rise (IPCC 2007, Karim and Mimura 2008, Unnikrishnan 2006, Webster 2008). This means that the Government of Bangladesh should pay even more attention to proactive risk reduction measures, building on the experience of what has worked well in the past.

Sidr and Nargis: Comparison of Two Cyclones in Indian Ocean

Although only 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 the high population density and poor governance in some of the exposed countries in this region.

In 2007 and 2008, several cyclones with disastrous impacts 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 (Table 9-3) Sidr made landfall in Bangladesh on 15 November 2007 and caused about 4,200 fatalities. Nargis hit Myanmar on 2 May 2008 and caused over 138,000 fatalities (CRED 2009), making it the eighth deadliest cyclone ever recorded (Fritz et al. 2009).

[INSERT TABLE 9-3 HERE:
Table 9-3: Characteristics of tropical cyclone Nargis (2008) in Myanmar.]

Bangladesh has a significant historical record of large scale disasters and serious efforts to decrease the risk from tropical cyclones have been made by the Government Bangladesh in the past decades (Paul 2009). In additions to the measures mentioned earlier, a coastal reforestation program was initiated in Bangladesh in 1960, covering about 159,000 ha of coastal land, the riverine coastal belt, and abandoned embankments. The Sunderban mangroves and coastal forests proved to be effective attenuation buffers during Sidr, greatly reducing the impact of the storm surge (GoB 2008).

In contrast to Bangladesh, Myanmar has very little experience with previous powerful tropical cyclones. Prior to Nargis, Myanmar had experienced only one tropical cyclone disaster with more than 1000 fatalities since 1960 (CRED 2009). The landfall of Nargis was the first time in recorded history 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). Several unfavourable conditions joined hands to transform this hazardous event into a large scale disaster, the most important of which was the intensity of Nargis. 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 provide 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 (a government-owned newspaper published by the Ministry of information) 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).

Nargis, despite being both slightly less powerful than Sidr and affecting fewer exposed people, resulted in human losses that were 32 times higher than Sidr. Bangladesh and Myanmar are both very poor countries. In 2008, the estimated Growth Domestic Product per capita in purchasing power parity (GDPppp) for Bangladesh was $1,500, while it was $1,200 for Myanmar (CIA 2009). This relatively small difference in poverty cannot explain the discrepancy in the impacts of these events. The governance indicators developed by the World Bank (Kaufmann et al. 2010) suggest significant differences in the quality of governance between Bangladesh and Myanmar, notably in Voice and Accountability, Rule of Law, Regulatory Quality, and Government Effectiveness. Low quality of governance, and especially Voice and Accountability, was highlighted as a major vulnerability component for human mortality risk to tropical cyclones (Peduzzi et al., 2009).

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 (National Hurricane Center, April 6, 2006). 560,000 residents in western part of Cuba and 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) showed 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 (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.

Comparison of the management of the two hurricanes by the Mexican authorities, in the same month and year, highlights important issues in disaster risk management.

Following the early alert for Wilma, 98,000 people were evacuated, 27,000 tourists were brought to safer places, and 15,000 local inhabitants and tourists were taken to shelters (García et al., 2006). 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 got involved in order to re-establish the airport and tourist facilities as soon as possible. By December, most hotels and the sand lost from the beaches were re-established.

By comparison, the evacuation of Stan in 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 were living 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 no or scarce 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.

Comparing the government responses to these two hurricanes in the same month, it is possible to note vastly different official actions in terms of early warning, evacuation and reconstruction. Federal attention appears to have been focused on Wilma, which affected Cancun, an international beach resort. The tourists and local inhabitants in Cancun were evacuated efficiently, and a massive recovery support strategy restored almost all services and hotels within two months. Meanwhile, the damages inflicted by Stan in the mountain regions of Chiapas were more serious, and the affected population did not have any form of insurance due to their high social vulnerability. The inadequate response to Stan left the poor indigenous groups with limited advice, insufficient disaster relief and scant reconstruction, especially in the highest and most marginal mountain regions.

Concluding Remarks

Comparative studies of the disaster management practices for tropical cyclones demonstrate that the choices and outcomes for response to climatic extremes events are complicated by multiple interacting processes, and competing priorities. The government response to similar extreme events may be quite different in neighbouring countries, or even within the same country.

Tropical cyclone risk management strategies in coastal regions that anticipate and plan for the effective of climate change, along with continuing changes in vulnerability and it causal processes, increase resilience in potentially affected communities. International cooperation and investments in forecasting and implementation of improved early warning systems, evacuation plans, infrastructures, protection of healthy ecosystems, and post-disaster support service to disperse the recovery funds to the victims efficiently are essential in coping with extreme tropical cyclone events.

Climate change adaptation, supported by disaster risk management, is most effectively pursued by understanding the diverse ways in which social processes contribute to the creation, management, and reduction of disaster risk. For developing countries, understanding and managing disaster risk from a development and development planning perspective is the key to a coherent strategy for climate change adaptation and disaster risk reduction.

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Case Study 9.2.2. Urban Heatwaves – The European Heatwaves of 2003 and 2006

Background

Extreme heat is a prevalent public health concern throughout the temperate regions of the world (Kovats, et al. 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 (Earth Observatory 2008; BBC 2002), Australia (Victorian Government Department of Sustainability and Environment 2008) and Europe (Robine et al. 2008; Founda and Giannakopoulos 2009), and there is consensus that climate change is very likely to increase the frequency of extreme heat events (SREX chap 3). As with other types of hazards, extreme heat can have disastrous consequences, particularly for very vulnerable populations. Risk from extreme heat is a function of hazard severity and population vulnerability. Extreme hazards do not necessarily translate into extreme impacts if vulnerability is low. It is important, therefore, to consider factors that contribute to hazard exposure and population vulnerability. Recent literature has identified a host of factors that can amplify or dampen hazard exposure. Experience with past heat waves and public health interventions suggest that it is possible to manipulate many of these variables to reduce both exposure and vulnerability and thereby limit the impacts that extreme heat hazards present.

Social and Biological Vulnerabilities to Heatwaves

Several factors influence vulnerability to heat-related illness and death. Most of the research related to such vulnerability is derived from experiences in industrialized nations. Several 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, babies and young children 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 (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 et al. 2003; Ebi and Meehl 2007). Older persons may also be more likely to be isolated and living alone than younger persons (Naughton 2002; Semenza 2005).

A wide range of socio-economic factors is associated with increased vulnerability. 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 et al. 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. 2009). Other groups, like the homeless and workers, are particularly vulnerable because of their living and working conditions (Yip et al. 2008).

Impact of Urban Infrastructures

As soon as circumstances permit, by addressing vulnerabilities in urban areas, much benefit will be accrued. About half the world's population lives 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 (United Nations 2008). 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 local heat production affects the urban thermal budget (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 and evapotranspiration 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 et al. 2007). High temperatures can also affect transport networks when heat damages roads and railtracks. Within cities, outdoor temperatures can vary significantly, some work has found by as much as 5ºC (Konopacki et al. 2001; Rosenzweig and Solecki 2005).

Systems of power generation and transmission partly explain vulnerability since electricity supply underpins air-conditioning and refrigeration, a significant adaptation strategy particularly in developed countries, but one that is also at increased risk of failure during a heat wave. Demand for electricity to power air-conditioning and refrigeration units is likely to increase with rising ambient temperatures. Areas with lower margins face increased risk of disruptions to generating resources and transmission under excessive heat events.

In addition to increased demand, there can be a risk of reduced output from power generating plants (UNEP 2004). The ability of inland thermal power plants, both conventional and nuclear, to cool their generators down is restricted by rising river temperatures. Additionally, fluctuating levels of water availability will affect energy outputs of hydropower complexes. During the summer 2003 in France, six power plants were shut down and others had to control their output (Létard et al. 2004).

<u>Description of the Events</u>

During the first two weeks of August 2003, temperatures in Europe soared far above historical norms. The heatwave stretched across much of Western Europe, but France was particularly affected (InVS 2003). Maximum temperatures recorded in Paris, for example, remained mostly in the range of 35°-40°C between 4th and 12th August, while minimum temperatures recorded by the same weather station remained almost continuously above 23°C between 7th and 14th August (Météo France 2003). The European heat wave had significant health impacts (Lagadec 2004). Initial estimates put the death toll across Europe over the first two weeks of August in the range of 35,000 and costs were estimated to exceed 13 billion euros (UNEP 2004, SREX chap 3), while it has been estimated that mortality over the entire summer could have reached about 70,000 (Robine et al. 2008). There were 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 (Grynszpan 2003; Kosatsky 2005; Fouillet, Rey et al. 2006) 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; Lagadec 2004; Robine et al. 2008; Pirard et al. 2005). 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 Regional Office for Europe 2006). France, the country hardest hit, developed a national heat wave plan, surveillance activities, clinical treatment guidelines for heat related illness, identification of vulnerable populations, infrastructure improvements, and home visiting plans for future heat waves (Laaidi, Pascal et al. 2004).

Three years later, between 10th and 28th July 2006, Europe experienced another major heat wave. In France, it ranked as the second most severe heatwave since 1950, the most severe having been the one in 2003 (Fouillet et al 2008; Météo France 2006). Although the 2003 heatwave lasted a few days longer than the 2006 one, it was less intense and did not cover as large a geographical area. Across France, recorded maximum temperatures soared to 39°-40°C (compared with 40°-44°C in 2003), while minimum recorded temperatures reached 19°-23°C (compared with 23°-25°C in 2003) (Météo France 2006). Based on a historical model, the temperatures were expected to cause around 6,452 excess deaths in France alone, yet only around 2,065 excess deaths were recorded (Fouillet et al. 2008). The difference in impact between the heatwaves in 2003 and 2006 may be at least partly attributed to the difference in the intensity and geographic scope of the hazard. It has been hypothesised that, in France at least, some decrease in mortality may also 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 may demonstrate 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 2010a), vulnerability mapping (Reid, O'Neill 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 (Bernard and McGeehin 2004; O'Neill et al. 2009; Reid, O'Neill et al. 2009; Hajat et al. 2010; Silva et al. 2010).

Interventions

Adapting the Urban Infrastructure

Several types of infrastructural measures can be taken to prevent negative outcomes of extreme heat events. 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 emissivity in urban areas (Silva et al. 2010; Yip et al. 2008). Reducing energy consumption in buildings can improve resilience, since then localized systems are less dependent on vulnerable energy infrastructure. In addition, by better insulating residential dwellings, people would suffer less effect from extreme heat. Financial incentives have been tested in some 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).

Public Health Approaches to Reducing Exposure

The risks associated with extreme heat hazards can be reduced by lowering the likelihood of exposure and reducing vulnerability. 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. In some cases, departments of emergency management lead the endeavour, while in others public health-related agencies are most responsible (McCormick 2010b).

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 during heatwave events dropped by 49% in Milwaukee, Wisconsin between 1995 and 1999, but this was not entirely attributable to differences between two heat waves in those years (Weisskopf et al. 2002). Evidence has also indicated that interventions in Philadelphia may 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). 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 2007).

Heat preparedness plans vary around the world. Philadelphia, Pennsylvania, one of the first US cities to begin a heat preparedness plan, has a ten-part program that integrates a “block captain” system where local leaders are asked to notify community members of dangerous heat (McCormick 2010b; Sheridan 2006). Programs like the Philadelphia program that utilize social networks have the capacity to shape behavior since networks can facilitate the sharing of expertise and resources across stakeholders, but may also contribute to vulnerability (Crabbé and Robin 2006). 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 (reference?).

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.

Communication and Education

One particularly difficult aspect of heat preparedness is communicating risks. In many locations populations are unaware of their risk and heatwave warning systems go largely unheeded (Luber and McGeehin 2008). 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, Wolf et al. 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 et al. 2008). Older adults may depend on numerous tools and strategies to address their special needs (Aldrich and William 2008). More generally, research shows that communication about heat preparedness should be centered around engaging with communities in order to increase awareness (Smoyer-Tomic and Rainham 2001).

Assessing Heat Mortality

Assessing excess mortality related is the most widely used means of assessing the health impact of extreme heat events. Mortality is likely to represent only the ‘tip of the iceberg’ of heat-related health effects; however it is more widely and accurately reported than morbidity, which explains its appeal as a data source. Nonetheless, assessing heat mortality presents particular challenges. 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 et al. 2006). For example, 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). 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.

Lessons Identified and Concluding Remarks

With climate change, heatwaves are very likely to increase in frequency and severity in many parts of the world (SREX chap 4). Urban settings are especially susceptible to heatwaves, even and possibly more so in highly developed countries. Smarter urban planning, improvements in existing housing stock and critical infrastructures and effective public health measures will assist in facilitating climate change adaptation.

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.

With understanding of local conditions and experiences and current and projected risks, it will be possible to develop strategies for improving disaster risk reduction in the context of climate change.The specificity of heat risks to particular sub-populations can facilitate appropriate interventions and preparedness.

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 also methodological difficulties in describing individual vulnerability that need further exploration.

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Case Study 9.2.3. Drought, Its Effects and Management

Introduction

Droughts have been a part of our environment since the beginning of recorded history, and humanity's survival may be testimony only to its capacity to endure this climatic phenomenon. Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (Hagman 1984). As drought has different types and different impacts based on geographic locations, examples of the complex ways in which extreme events, long term trends, and high vulnerability interact to produce extreme impacts in different geographical locations.

Drought in the Sahel

Sahel is located on the southern margins of the Sahara desert, reflecting the zone where the ecology and the climate start to make settlement possible again (Nyong et al., 2007). Prolonged periods of drought in the Sahel have been experienced throughout the past 5,000 years of agriculture, reflecting the way in which the southern boundary of the desert fluctuates. After two decades of wet conditions in the 1950s and 1960s, the most significant severe drought was in the early 1970s (Hulme, 1992, 1996, 2001, Batterbury and Warren, 2001).

The severe drought 1970-1990 made the society and ecosystems more vulnerable to impacts from extreme events (Mortimore, 1998), and at the same time the Sahelian population increased rapidly with an average annual growth of 2.6 percent (UNPP, 2006). This increase appears to be a main cause of degradation of ecosystems by humans with over –use of natural resources in the region through overgrazing, deforestation, over-cultivation, intensive irrigation, and poor land management (Olsson 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). According to the report of Africa Committee on Sustainable Development under the aegis of United Nations Economic Commission for Africa (UN-ECA Report, 2007), it is estimated that some 60 million will eventually move from the desertified areas of sub-Saharan Africa towards Northern Africa and Europe by the year 2020.

Divergent views about recent rainfall trends over Sahel, with some of recent work suggesting the drought ended during 1990s (Ozer et al. 2003), while others concluded that there was only a partial rainfall recovery (Nicholson, 2005, Lebel and Ali 2009). Recent studies showed a consistent trend for greening in some areas of the region during the last two decades across the Sahel that could be explained by the increasing rainfall and the changes of land use (Olsson et al, 2005). Despite a rainfall recovery in some parts, it is clear that globally the Sahel drought is real and characterized by a greater inter-annual variability (Ali and Lebel, 2009). Predicting how the Sahel rainfall trend will evolve is very uncertain to, according different models for climate projections (IPCC, 2007, Biasutti et al. 2008, Giannini et al. 2008).

Drought in Ethiopia

Historical accounts of famines in Ethiopia go as far back as the 9th century, however, evidence on its impact on health only started to emerge from the 15th century onwards (Taye A, et al 2010). During 1999/2000, great parts of Ethiopia experienced a period of famine which was recognized internationally. The rainfall was high in 1998 but 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 (Emmelin et al 2008). Mortality peaks reflect epidemics of malaria and diarrheal 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). In extreme droughts such as this one in Ethiopia in 1999/2000, it has been concluded that, the poorest in the farming communities are vulnerable to major health 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.

Besides substantial economic and social impacts, the health impacts of a severe famine due to drought and/or other causes are hard to measure. However, one survey conducted in 2000 in Gode district 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), which was about double the crude mortality rate of 3.2/10,000 per day (95% CI 2.4 – 3.8) however with 225 (76.8%) of all the deaths having occurred before any intervention had arrived (Salama 2001, Taye et al 2010) The mortality rate was declining by the time intervention was introduced but then it increased, The increase in mortality rate may have been due to influx of non-immune malnourished people to the centralized intervention centers. Almost 80% of all deaths were among children aged 14 years or younger and around 8% occurred among older persons. Wasting, together with one of four major communicable diseases of measles, diarrhoea, malaria and respiratory tract infection, contributed to 206 (70.3%) deaths. The cause of death was different before and after the intervention with:

- 29% versus 15% attributed to wasting alone before intervention
- After intervention respectively, 55% versus 50% attributed to wasting and one of the four major communicable diseases
- 16% versus 35% to one of the four communicable diseases alone.

This indicates that infectious disease had become a more prominent cause of death after the start of intervention ($p < 0.01$ for all) (Salama 2001, Taye A, et al, 2010)

Drought in Syria

Rainfall represents 68.5% of the available water sources in Syria. However due to drought the deficit in available water has been estimated of about 651 million M^3 during the years 1995-2005, and this has increased having an impact on the rainfed agriculture areas, (Nashawatii, 2010). The vegetation cover has been declined in most of areas suffering from drought, (Nashawatii, 2010). It has been determined that for not less than 12 years out of the last 24 years that these drought areas affected by the reduction in rainfall, (Erian 2010).

The drought frequency increased during the agriculture seasons of 2004-2005 to 2009-2010. This forced the local population to immigrate from the northwestern part of Syria and from the Syrian steppe as the winter rainfall was not enough to satisfy cereal crops water requirements and 25% of the animal population in the steppe areas were lost due to the continued drought cycles, (Erian, 2010 and Nashawatii, 2010). During the 2009-2010 growing season, rainfall conditions have been extremely mixed with the most favorable accumulation of rain occurring in western and northwestern regions. Southern, southeastern and northeastern regions all suffered continuing drought conditions and had reduced rainfall, (USDA, 2010). The provinces primarily affected by poor rainfall included the top four wheat producing area which account for 75% of total wheat production in Syria (Al-Hasakah, Ar-Raqqah, Aleppo or Halab, and Dier ez-Zor DATE). Favorable rainfall in April and May is critical to successful growing seasons, and in season 2009-2010 non-irrigated crops were already failing in late March. April rainfall was extremely low throughout northern and northeastern wheat regions this year, causing even greater moisture stress and decimating crop yield potential (USDA, 2010).

Other impacts of drought have included increasing desertification with a greater number of dust storms days (Nashawatii, 2010). Health impacts from dust storm days in Dair El Zohr area in Syria showed that 60% of population, mainly in rural areas, had breathing problems with 70% experiencing eye diseases, 25% suffered digestion problems and emergency cases increasing by 380% .(Al Ebaid, 2000). The toxicity of coarse particles is substantially less than that of fine particles (Al Ebaid, 2000). ,

Drought in South America

Droughts can be due to many climactic events on of which can be the change in weather patterns during an ENSO event (El Niño/La Niña-Southern Oscillation, or ENSO, a climate pattern that occurs across the tropical Pacific Ocean on average every five years). This alters regions of high and low pressures around the globe. This results in 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 southeastern Africa, India, China and northeastern 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 El Nino caused severe droughts and forest fires in northeast Brazil. (World Meteorological Organization 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 southwestern Amazonia experienced one of the most intense droughts of the last hundred years. (Marengo et al 2007) The drought severely affected human population along the main channel of the Amazon River and its western and southwestern 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 from February 2006.

One of the worst droughts in 50 years occurred in 2008 and 2009, which 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.

Drought Effects

Few extreme events are as economically and ecologically disruptive as drought, which affects millions of people in the world each year (Wilhite 2000). Severe drought conditions can profoundly impact agriculture, water resources, tourism, ecosystems, and basic human welfare (see also chapter 3 for a discussion of these aspects). Over the United States, drought causes $6–8 billion per year in damages on average, but as much as $40 billion in 1988, Federal Emergency Management Agency (FEMA 1995). EM/DAT data showed that about 2.63 million people were affected by hydro-metrological disasters globally during 1997-2006 with about 41.82% are affected by drought, and 38.87% of them were affected during 2002 (World Disaster Report 2007),. During 1997-2006, hydro-metrological disasters caused an estimated damage of US$ 66.8 billion per year on average out of this 4.62% caused by drought. Average number of people reported killed by drought in million per year are, Asia (81.11), Africa (26.69), Americas (2.57), Europe (0.14). The impacts of drought are likely to become ever more severe as a result of development processes and population increases (Squires 2001). Droughts often stimulate sequences of actions and reactions leading to long-term land degradation, (Erian 2010).

Dust storms are related to drought, precipitation, soil moisture, beside other factors such as land use and land cover practices, and other human activities. A lack of precipitation often triggers agricultural and hydrological droughts, but other factors, including more intense but less frequent precipitation, poor water management, and erosion, can also cause or enhance these droughts. For example, overgrazing led to elevated erosion and dust storms that amplified the Dust Bowl drought of the 1930s over the Great Plains in North America, (Cook et al 2009). Dust storms have increased in the Mediterranean and East Asia regions over the last decade These storms can travel over large parts of Asia, Africa, even affecting North America and Europe, (McKendry et al.2001). 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 may be linked to lethal epidemics. A gram of desert soil may contain as many as 1 billion bacterial cells, the presence of airborne dust should correspond with increased concentrations of airborne microorganisms, (Griffin 2006) dust storms resulted in the greatest mass of Asian dust transported to North America in at least the past 20 years and contributed significantly to surface PM levels across the U.S, (Zhao etal., 2007).

Dust storms are also playing an important role in the supply of nutrients and micronutrients to the oceans and to terrestrial ecosystems, (Shinn et al 2000, and 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 Km2, 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/Km2 and main portion of the dust storm on April 07,2001 contained 6.5 million tons of dust, (Yingxin et al, 2003).

Drought Management

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, (Wilhite 2005). White added that 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. The Arab Center for The Studies of Arid Zones and Dry Lands (ACSAD), headquarter in Syria works closely with the ministry of Agriculture in Syria, Jordon, Lebanon and Egypt for empowering their drought monitoring unit and develop drought strategy at the meantime other activities are ongoing for improving the productivity of rainfed areas which focus on reducing the adverse effects of drought have been underway for at least 2-3 decades. The tool box of ACSAD to deal with drought and Arid areas within Arab region includes activities such: water harvesting, supplementary irrigation, rehabilitating depredated areas, Conservation agriculture, Integrated Water Management System, Use of non-traditional Water and Increase Irrigation Efficiency, prepare potential Land Use Mapping, introduce conservation agriculture, adding manure to soil to improve its holding condition, recycled organic solid waste from farm residuals and add to soils, Follow crop rotation, produce new breeding cereal seeds tolerant to stresses such as drought, heat , salinity and diseases, Improve Small Cartel Productivity and give more capacity building, (ACSAD 2009, ACSAD/ GTZ 2010).

Lessons Identified

- Already water resources are stressed in some areas around the world and therefore highly vulnerable, especially with respect to competition for water supply between agriculture, power generation, urban areas, and environmental flows (high confidence) and salinization. Increased evaporation and possible decreases in rainfall in many areas would adversely affect water supply, agriculture, and the survival and reproduction of key species in parts of the world that depend on uncertain sources.
- Political issues play a role within drought risk management. Investment and promotion of inter-disciplinary dialogue to improve awareness and to define the issue and communication to address drought risk would be elements of effective response and such strategies are important. For those governments where there are risks of drought, they might wish to consider investing effort to develop these strategies and dialogues.
- Drought needs a cross-cutting approach and therefore requires a wide range of inputs (e.g. cultural, socio-economic, etc.). Accordingly drought management capacities could be strengthened, including capacities to develop integrated plans, if appropriate. Evaluation of risk management measures and practices could also be undertaken to determine if they are effective.
- The health impact of drought is complex and can cause long standing issues affecting health and livelihoods of successive generations. Robust surveillance systems to record impact on health and to inform action could contribute to understanding that impacts are reduced effectively.
- Drought has an impact on socio-economic stability particularly with migration from rural areas with water shortages and food scarcities.

- Better agreement on triggers for early warning and actions to improve preparedness within particularly vulnerable areas by changing land use and crop patterns, introducing new seed varieties more tolerant for drought, improve community socio-economical preparedness (assets, governance and technology) and create alternative economic opportunities.

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Case Study 9.2.4. Floods Managing Complex Interactions between Hydro-Meteorological and Hydro-Geological Processes

Floods are a major natural hazard in many regions of the world (Ahern et al 2005). According to the data of Munich Reinsurance Company, about half of all fatalities connected to natural disasters and 30% of the economic losses are caused by floods (Munich Re, 2001). Vulnerability and exposure are key determinants of disaster risk.

Catastrophic Floods in Mozambique – Lessons and Actions

Mozambique is very vulnerable to natural disasters especially floods because of climatic factors and geographical position. 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. Therefore the development and function of early warning and flood control systems for Mozambique need to be based on a close collaboration with other countries of the Southern Africa Development Community (SADC).

Floods in 2000: Event Summary and Impacts on the Population and Economy

Natural disasters are one of the main risks to the achievement of Mozambique's poverty reduction strategy. From 1965 to 1998, there were twelve major floods, nine major droughts and four major cyclone disasters (World Bank, 2005). One of the most destructive floods has occurred in the winter 2000 when the coast of Mozambique has been attacked by a series of tropical cyclones that has led to extensive flooding (Van Biljon, 2000). Floods affected 12.1% of the population in five provinces and 699 lives were lost. About 90 % of the irrigation structure in the affected areas was damaged. On the estimation of the World Bank the direct losses amount to US $273 million, and the lost production amounts to $247 million (UN General Assembly, 2000).

The epidemiological study during the floods in the most affected area in the mid south of Mozambique detected the infectious diseases in 85% of all of patients, predominantly malaria, respiratory infectious diseases, and diarrhea (Kondo et al 2002). 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. The increase in infectious disease incidence was connected to the heightening of the associated risk factors: increase of population density; worsening temporary living conditions; the degeneration of quality of drinking water; and the deterioration of physical strength due to lack of food.

Role of Key Personnel and Agencies

One of the major problems for authorities is timely pre-warning of people about the potential occurrence of a natural disaster. It allows not only the opportunity to reduce material losses, but, in a number of cases, to save human lives (Environment Agency 2010). Success and effectiveness of warnings depend not only on accuracy of the forecast, but also their delivery in adequate time before the disaster to put in place prevention strategies. In addition it is very important that a warning has been received by each person in the disaster zone. The warnings should be understandable for people without special training. In 2000 most people in the affected areas received warnings issued by the water management about the rising river levels 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 understanding the communication systems and their role in facilitating CCA, as it is through good communication that knowledge transfer and innovation can enhance early warning systems. Poor communication flow can impede the awareness of risk determinants diminishing the ability to adapt to climate change.

Lessons and Action after Floods 2000

The important problem is the sustainability of the monitoring and forecasting system. In 2000 in Mozambique there were problems with the installation and maintenance of in situ gauging equipment due to financial constraints. In addition, the hydrological and precipitation gauges are often washed away and many key stations were destroyed, leaving Mozambican water authorities with no source of information on the actual magnitude of floodwater (Asante et al. 2005). The enormous material damage and human losses during the floods in Mozambique in 2000 were associated with the following problems:

- *Institutional problems*. In 1999 National Policy on Disaster Management in Mozambique only began to shift from a reactive to a proactive approach in disaster management aimed at developing a culture of prevention (World Bank 2005)
- *Technological problems*. Before the floods of 2000 active observational hydro-meteorological measurement in Mozambique had been rare. 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 trans-boundary river basins.
- *Financial problems*. Insufficient budgetary resources singled out for the creation, development and maintenance of the National Policy on Disaster Management.

Mozambique's government learned some lessons from the devastating floods that hit the country in 2000. 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) (Foley 2007, The National Action Plan for the Reduction of Absolute Poverty 2001, Republic of Mozambique Action Plan 2006). In 2006 the government adopted a Master Plan, which provides a comprehensive strategy for dealing with Mozambique's vulnerability to natural disasters. 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. 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. 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.

Event Summary of Floods 2007

Seven years after the catastrophic floods in 2000 a similar situation with floods in Mozambique was repeated, but the country was ready for these dangers in a greater extent than before. Between December 2006 and February 2007, strong rains across northern and the central Mozambique together with a serious downpour in neighboring countries, have led to flooding in the Zambezi River basin (DREF Bulletin, 2007). Additional flooding has been linked with the approach of tropical cyclone Favio which struck the Búzi area at the end of February 2007. During flood period in the southern coast of Mozambique, nine people were killed, 70 people were injured. The heavy rains and floods damaged health centers, Public and administrative buildings, drug stocks and medical equipment and affected safe water and sanitation facilities (UN OCHA 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 Inhambane Province (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. On data of the World Food Program (WFP) the floods affected 285,000 people and the cyclone 150,000 more (WFP Mozambique, 2007). USAID estimated that 331,500 people had been affected by the flood and 162,770 by the cyclone (USAID Mozambique 2007).

Activities of Local Authorities and International Organizations before and during Floods

After flooding 2000 authorities and agencies of Mozambique together with foreign partners have executed great activities on preparation for acts of natural disasters. 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 and water level at strategic points along the Buzi river basin. If precipitation is particularly heavy or the river reaches critical levels, this information is passed on by radio and blue, yellow or red flags are raised depending on the flood-alert level. This is a good example of a scientific high technology adaptation for DRM that has been tailored to the local community and capability.

To prevent outbreaks of infectious diseases 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. To address the increased risk of vector-borne diseases USAID/OFDA provided financial means for the procurement and transportation insecticide-treated mosquito nets to flood-affected populations. 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 and WFT provided food assistance to people in affected zones. 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 to more than 23,000 families.

<u>Lessons Identified from Other Flood Events</u>

South Korea: Impact Determined by Previous State of the Environment

The impact of an extreme event can be greatly 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; 2004). 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 82mm of hourly rainfall at Pyeongchang County (Gangwon Province, 2007). The rainfall led to severe landslides, which brought a great amount of debris into streams, and consequently 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).
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Since the damaged areas were not highly populated, nor farmed, the total damage was not high enough for the event to be classified as a major disaster. However, damages 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 declared 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, and started a program to control soil erosion and to build dams in potential risk areas to prevent debris from flowing downstream (Gangwon Province, 2007).

Russia Republic of North Ossetia

The accumulation of the effects of many small disasters may be as damaging or worse than one large disaster.

In September 2002, a huge natural catastrophe destroyed the Genaldon valley in the Russian Republic of North Ossetia. Enormous masses of ice mixed with water and stone broke loose and rushed down the valley with high velocity, devastating everything along the way and stripping the slopes of forest and loose sediments up to a height of over 100 m. The avalanche was stopped by the Skalistyi mountain range, which runs perpendicular to the valley, but glacial debris flow burst through and brought ruin for the next 17 km.

The formed rock/ice avalanche had a volume of about 100.106 m^3 and travelled down the Genaldon valley for 20 km. A mudflow, however, continued moving for another 15 km and stopped in 4 km before reaching the town of Gisel. The avalanche and the mudflow caused the death of about 140 people and destroyed important traffic routes, residential buildings and other infrastructures. The ice/debris deposits formed several marginal lakes of up to 5,000,000,000 m^3 of water. Potential floods from these lakes were an imminent threat to the downstream areas

(Kaab, 2003a; Haeberli et al., 2005). The village of Nizhnii Karmadon and several rest homes along the Genaldon River below the gorge were completely destroyed.

According to investigations of some scientists the premature surge of the glacier and huge scale of the catastrophe were provoked by complex of factors such as:

- Accumulation of great quantities of water in and under the glacier, due to special climatic and meteorological conditions;
- Volcanic activity; this caused additional melting of the bottom of the glacier;
- In addition, ice and rock falls overloaded the rear part of the glacier and increased the tension in its body.
- Tectonic structure of the region: the Kolka valley is situated in a zone of large sub-latitudinal faults where displacements of individual blocks and earthquakes are highly probable.
- A direct trigger for the glacier surge might have been just another minor fall, a small earthquake, or simply a destructive process inside the glacier that created a critical tension in its body. (Kotlyakov V.M., 2004; Huggell C., 2005).

England to Wales: The Impact of Heavy Rainfall

In England and Wales the rainfall during June and July 2007 was unprecedented (Pitt Review 2008). The severe flooding which followed came after the wettest ever May to July period since national records began in 1766. The UK Meterological Office records show that the total cumulative rainfall in May, June and July 2007 averaged 395.1mm across England and Wales – well over double usual levels. This exceptionally heavy rain resulted in two severe and disruptive flooding events; the first during the week of 20 June and the second during the week of 18 July. A clear indication of where the heavy rain fell can be seen in the maps of precipitation levels for England and Wales during 24–25 June and 19–20 July 2007 (Figure 9-1).

[INSERT FIGURE 9-1 HERE:
Figure 9-1: Precipitation levels for England and Wales during 24-25 June and 19-20 July 2007.]

The consequences of the rain was severe flooding with approximately 55,000 properties flooded, around 7,000 people were rescued from the flood waters by the emergency services, adverse health effects were reported and 13 people died. In Yorkshire and Humberside approximately 48,000 households and nearly 7,300 businesses were flooded causing billions of pounds worth of damage. In Gloucestershire, the Mythe Water treatment works was flooded and left 350,000 people without any mains water supply, and the hospitals were also greatly affected (Whitely 2007).

The UK also had the largest loss of essential services since World War II, with almost half a million people without mains water or electricity. Even telecommunications were disrupted. Transport networks failed, a dam breach was narrowly averted and emergency facilities were put out of action. When the Pitt Public Enquiry sat in 2008 they were told that the insurance industry expected to pay out over £3 billion with other substantial costs being met by central government, local public bodies, businesses and private individuals (Environment Agency 2010).

This public enquiry recommended four main areas to improve response

- Improve the quality of flood warnings (Environment Agency 2009)
- Improve flood risk management to protect communities through robust building and planning controls
- Improve protection within critical infrastructure to avoid the loss of essential services such as water and power and for all sectors to be more open about risk
- Improve UK knowledge by learning from good experience abroad and in particular better advice on how to protect their families and homes; raise the awareness through education and publicity programmes; learn more on how people can stay healthy to speed up the whole process of recovery

Conclusion

Floods show that the efficient managing of the risks of extreme events and disasters is vital to advance climate change adaptation. Studying cases of extreme natural phenomena with the purpose of creating reliable systems of monitoring, forecasting and informing of the population on threat of natural accidents and reactions to these threats for the prevention or mitigations of negative consequences including health impacts is hugely important (Caldin and Murray 2011). In particular:

- Long-term adaptation to extremes of climate and associated hydrologic extremes requires understanding and are important. Governments may wish to consider investing effort in developing strategies for climate smart Disaster Risk Management (EEA 2010).
- The importance of adapting disaster risk management to new climate change situations becomes very apparent when disasters cross international boundaries (WHO Europe 2010).
- Risk perception and awareness, adaptation and risk reduction effectiveness depend on appropriate risk communication (Whittle et al 2010).
- Natural disasters not only cause financial losses and casualties, but also cause people to think about how to prevent or reduce losses from disasters in future. Formulation of a reasonable strategy of the disaster risks management in the conditions of increasing threats of extreme natural disasters is one of the main tasks of adaptation to climate change (Cosford 2009).

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Case Study 9.2.5. Complex Disasters Induced by Hot Weather - Victoria, Australia: Reducing Wildfire Suppression Costs and Ecological Disasters

<u>Introduction</u>

Climate change is expected to increase global temperature and changing rainfall patterns. These climatic changes are likely to increase the risk of extreme weather induced disasters such as droughts, heat waves and wildfires. The effects may vary by sub-regions and localities, but in general the following may be expected to take place: (i) increase in temperature and decrease in mean precipitation leads to an increase in the frequency and severity of drought and heat waves; (ii) Severe drought and heat waves leads to an increase in wildfires; and (iii) severe wildfire causes severe floods and landslides in case of greater intensity of rain. The goals of this case are to present weather-related hazards, their effects and potential impacts and provide an overview of measures to mitigate and manage these risks.

Effects of Extreme Weather-Induced Disasters

With climate change, hot dry conditions are very likely to become more frequent. 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 experienced a decline in average rainfall of 14 % (DSE 2008). Victoria has been the warmest on record, breaking records going back 154 years over the last decade (State Government of Victoria 2009; Parliament of Victoria 2009). In central Victoria the 12-year rainfall totals have been around 10 to 20% below the 1961 – 1990 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 555mm, compared with a long-term average (1961 – 1990) of 653mm (Australian Government 2009).

The number of dry spells and the risk of drought are likely to increase in SEM, notably in southern Europe (Lehner et al. 2006). Annual temperatures are projected to increase in SEM and the Mediterranean 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. Globally droughts are the second most geographically extensive hazard after floods i.e., covering 7.5% and 11% of the global land area each. The combination of a decrease in rainfall and increased evaporation will lead to more severe and longer-lasting droughts and heat waves in some areas. Australia is the driest inhabited continent even though some areas have annual rainfall of over 1200mm. The average elevation of Australia is less than 300m, compared with the world's mean of about 700m. This low elevation, coupled with the latitudinal position extending from 10°41'S in the north to $43^0$39'S in the south, contributes to the general aridity of Australia. More than one-fifth of its land area is desert, more than two-thirds being classified as arid or semi-arid, unsuitable for settlement.

The impacts of an extreme event can be greatly determined by the prevailing condition of the environment. Wildfire behavior is modified by climate, forest management, and fire suppression (Allen et al., 2002; Noss et al., 2006), and understanding the reasons for changing wildfires is further complicated by changes in fire reporting over the period of record. The maximum temperature 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). However, recent changes in climate were likely the main drivers for increases in area burned in the western United States (Westerling et al., 2006), Canada (Gillett et al., 2004; Kasischke and Turetsky, 2006; Girardin, 2007) and Australia (Australian Government 2009).

Impacts of Extreme Weather-Induced Disasters

The impacts of an extreme weather induced disasters can be greatly determined by the prevailing condition of the environment. Hotter temperatures and lower rainfalls lead to dryer forests resulting in larger and more serious fires. As a leading case to illustrate the impacts of extreme weather induced disaster, the Victoria bushfires, 7 February 2009 well demonstrate the inter-relationship among the extreme weather induced disasters such as droughts, heat waves and wildfires. And then fire examples both in Europe and Republic of Korea follows to illustrate their effects and potential impacts.

Droughts in Melbourne

The day of the fires came after 12years of the state's hottest and longest drought (Trewin and Vermont, 2010). Over this period, the whole of south-east Australia suffered a severe and protracted drought which is without historical precedent. Rainfall deciles for January and February 2009 indicate that both months are very much below average

(Australian Government 2009). The 2009 winter season in Australia brought below normal precipitation across much of the country. 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). Decreased water supply along with warmer temperatures is likely to increase drought risk and severity (CSIRO, 2007). The most significant and inherent risk in drought is insufficient water supply for Victoria. Not only droughts will very likely increase the extreme fire danger conditions but also severe wildfire causes severe drought by contamination of drinking water by ash and debris inflow into reservoirs in the burned catchments. Forested catchment areas supplying five of Victoria's nine major dams were affected by the fires, with the worst affected being Maroondah Reservoir and O'Shannassy Reservoir. As of 17 February, over ten billion litres of water had been shifted out of affected dams into others.

Heat Waves in Victoria

The heat waves began in South Australia on 25 January but became more widespread over southeast Australia by 27 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 which temperature was the second-highest on record behind 45.6°C on 13 January 1939. Overnight temperatures were also extremely high with Melbourne Airport's minimum of 30.5°C on the 29 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 (State Government of Victoria 2009). 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 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 from 26 January to 1 February 2009, 25% increase in total emergency cases and a 46% increase over the three hottest days. 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 (State Government of Victoria 2009; Parliament of Victoria 2009). 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. However, excess mortality provides a measure of impact of heat waves. 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. Reportable deaths in those 65 years and older were more than doubled for the same period in 2008 (State Government of Victoria 2009; Parliament of Victoria 2009).

Victoria's Bushfire

The intensity and speed a bushfire travels depends on amount and arrangement of the fine dead fuel, moisture content of the dead fuel, wind speed near the flaming zone and terrain and slope. Fire danger is the sum of all factors that affect the inception, spread, and difficulty of control of fires, and the damage they cause. The total concept of fire danger is impossible to embody in a single, practical index. However, the McArthur Forest Fire Danger Index (FDI) is based around providing a relative measure of the difficulty of suppression for a standard fuel type. The FDI reached unprecedented levels, ranging from 120 to over 200 around 7 February 2009. This was higher than the fire weather conditions experienced on Black Friday in 1939 and Ash Wednesday in 1983 (Bureau of Meteorology 2009). Over this period, temperatures were being reached, 46.4 °C in Melbourne, humidity levels dropped to as low as 6% and rainfall deciles for January 2009 are very much below average. 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.

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 centers 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.

Wild Fires in Europe and Asia

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. In Russia in 2010, a similar complex heat event occurred as in Victoria in 2009 with drought and forest fire, which the smoke resulting in air pollution causing adverse health impacts. 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 Greek 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 (Tolika et al. 2007). 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 also 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. In the case of the Republic of Korea in 2000, the dry and windy climate caused by foehn winds during spring, and high-density planting on steep slopes which is likely to increase risk of wildfires can accelerate flame propagation over a wide area. Over nine days, 23,448 ha of forest area rapidly burned due to propagation under heavy winds, with a maximum instantaneous wind speed of 25 m/s (Kim et al. 2008). These damages, especially on the steep mountainsides led to severe landslides, which brought a great amount of debris into stream, reduced flow capacity and even blocked the channel before the channel structures especially small bridges, and consequently significant flooding in case of greater intensity of rain, most notably from Typhoon RUSA in 2002.

Management of Extreme Weather-Induced Disasters

The key adaptation measures for Melbourne's drought 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. Melbourne has 10 major reservoirs and they store and hold up to 1,810,500 million liters of water. As storm water volume in Melbourne is almost equal to potable water consumption, this is a valuable resource. The water restriction regime of Melbourne has helped manage the significant drought issues of recent years. Another key focus fire season is protecting the Upper Yarra and Thomson catchments, which hold the majority of Melbourne's water supply and were largely untouched by Black Saturday. In order to prevent contamination of Melbourne's drinking water by ash and debris, Melbourne Water has moved water out of fire-affected catchment areas to other catchments.

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. They are also trying to develop a toolkit to assist local councils in the preparation of heat wave response that could be integrated with existing local government public health and/or emergency management plans.

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 minimized 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).

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). 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). 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). The Korea government started program for stream design criteria to cope with changes in fire and other climate and to build debris barrier in potential risk areas to prevent debris from flowing down stream.

Lessons Identified

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). The most significant extreme events for Melbourne likely to be exacerbated by these climate changes are drought, heat waves and wildfires. 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).

A key adaptation measure for Melbourne to lessen the impact of drought could include storm water harvesting, the volume of which is considered to be almost equal to potable water consumption. Investment and development of multiple reservoirs operating a shared program to define the issue and communication to move water out of fire-affected catchment areas to other catchments would possibly prevent contamination of Melbourne's drinking water by ash and debris.

Strengthening risk management capacities including (i) prior campaign for awareness, (ii) information and warning systems, (iii) translation levels of awareness and preparedness into universal action, (iv) sharing responsibility between government and the people and (v) enhancing managers' decision-making abilities to develop integrated plans could be part of future strategies.

High soil erosion rates in burned area are irreversible at the ecological time scale; therefore, it is a major potential impact of flood and wildfires. Political issues as well play a great role within the wildfire risk management and should be committed to create extreme event related plan and building codes for recovering ecosystem resilience in those abandoned lands to break degradation loops and promote secondary succession towards more mature, more resilient plant communities. In order to prevent severe flood damages in burned area, effective risk management such as stream design criteria to cope with changes in fire and other climate and to build debris barrier to prevent debris should keep in focus.

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Case Study 9.2.6. Complex Cold Climate Impacts - The Arctic and Dzud

Introduction

Climate change can create an especially complex vulnerability in cold climate regions. There are a number of factors that contribute to this trend. Primarily, due to the harsh environment in cold climate areas, there is a special relationship that develops between the residents that live there, their built environment and nature. People in such regions are dependent on natural resources and cycles and must therefore accommodate their environment. That relationship however, means that structures and patterns of foraging or cultivation have been built and developed to suit the current climate (Ford, 2010; Instanes et al., 2005; NRTEE, 2009; US Arctic Research Commission, 2003). This sort of climate-specific design does not generally allow for the redundancy and flexibility that are needed to accommodate a changing climate. To add to this vulnerability, changes are occurring at a faster rate than residents can adapt to them and the affected communities are often too isolated to receive adequate assistance from the rest of the nation (Ford, 2010; Paskal, 2010).

This case study will examine vulnerabilities in two different cold regions and their adaptive capacity. In Northern Canada, the focus will be on infrastructural vulnerabilities. For the Mongolian Dzud, it is the vulnerability of pastoral animal husbandry to extreme events. For both, adaptation is already required. The northern territories in Canada have witnessed the demise of several ice roads – important transportation arteries that ensure supplies and contact with the rest of the country- because the ice could not maintain a desired level of thickness. Similarly, hunting, foraging and agricultural traditions are no longer able to sustain Northern communities. In Mongolia, 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).

The Canadian North

In recent years, the northern regions of Canada have experienced the most rapid rates of climate warming in the country (Furgal and Prowse, 2008; McBean et *al*., 2005; Ford and Pearce, 2010; NRTEE, 2009). These trends are consistent with global ones, as the arctic regions have been warming at twice the rate as the rest of the world and faster than the most extreme projections had predicted (Anisimov *et al*., 2007; Environment Canada, 2010).[1] In 2004, the Arctic Climate Impact Assessment estimated that the Northwest passage would be completely open by the year 2050. In reality, this area has been navigable for the past four summers and an open channel is expected before 2020 (NRTEE, 2009). The accelerated rate of climate change is creating challenges for the communities in the North because they are unable to adapt quickly enough to match the emerging impacts. This trend will likely continue. According to the 2009 study by the Canadian National Round Table on the Environment and the Economy (NRTEE), annual average temperature is expected to rise by between 1 and 3° C over the next ten years. Specifically however, winter temperatures are set to rise by between 3 and 11°C with smaller changes projected for spring and summer, with temperatures rising to as warm as -7°C in the far North (NRTEE, 2009). In more southern regions, temperatures could extend into the positive realm. All three territories, the Yukon, Northwest Territories and Nunavut, are currently struggling to adapt to such drastic changes.

[INSERT FOOTNOTE 1:
http://www.apegga.org/Members/Presentations/AC2010/HeatherAuldEnvCanPermafrost.pdf]

The Canadian North Built Environment and Impacts of Climate Change

Infrastructure adaptation is very important because of the role that infrastructure plays in maintaining the social and economic functions of a community; the amount of money that is required to operate and maintain structures; and the long lifespan of each structure. Two main climate-related impacts that affect infrastructure are permafrost thaw and snow load. Addressing these impacts is a complex task as each impact affects different structures differently. In addition, there is a negative synergistic relationship between the impacts, whereby the combined effect is more damaging than that of the individual impact itself. For example, although increasing snow loads can have negative impacts on infrastructure on their own, the fact that many buildings have been structurally weakened by permafrost thaw, adds to the damage potential during any snow event.

Permafrost thaw

Permafrost thaw is one of the leading concerns in climate-related vulnerability because it is such an all-encompassing issue. As the temperature increases, permafrost, which requires consistent sub-zero temperatures to maintain its form and density, begins to thaw. The rate of thaw and the related implications for infrastructure stability depend on the temperature increase and the type of soil underneath the permafrost (Nielson, 2007). The following figure (Figure 9-2) highlights the different permafrost zones in Canada. Under a changing climate, it is difficult to tell where permafrost is most likely to thaw, but about half of Canada's permafrost zones are sensitive to small, short-term increases in temperature, causing soil to lose it's 'bearing capacity' (Nielson, 2007; NRTEE, 2009). Municipalities in the Discontinuous or Sporadic zones are likely to feel the impacts of a warming climate since permafrost is already in a non-continuous state within their region.

Permafrost thaw affects different types of infrastructure in radically different ways. In municipalities like Iqaluit, Nunavik and Yellowknife the following impacts have been observed (Nielson, 2007; NRTEE, 2009; Infrastructure Canada, 2006):

- Roads and airport runways have suffered from erosion, heaving, buckling and splitting.
- In Iqaluit, 59 houses have required foundation repair and/or restoration and other buildings have been identified as needing attention in the near future.
- Underground pipes and cables have been damaged by shifting and heaving earth, causing disruption to both the power and communication industries.
- Water distribution and wastewater treatment systems have experienced minor damages to their underground pipes and storage facilities.
- Underground containment structures that are used to manage toxins and tailings from mining operations, have begun to show signs of vulnerability related to permafrost thaw.

[INSERT FIGURE 9-2 HERE:
Figure 9-2: Canada's Permafrost Zones (NRTEE, 2009).]

The impacts of permafrost thaw on infrastructure have implications for the health, economic livelihood, safety and 'liveability' of northern Canadian communities. The costs of repairing and installing new technologies to adapt to climate change in existing infrastructure can range from several million, to multiple billions of dollars, depending on the extent of the damage and the type of infrastructure that is at risk (Infrastructure Canada, 2006). These costs are well beyond the financial reach of many communities (and indeed most provincial/territorial governments as well), thus limiting adaptive capacity in Northern municipalities.

Snow loading

In most Northern Canadian communities, buildings and roadways are built using historical snow load standards (Nielson, 2007; Auld and MacIver, 2005). This makes them particularly vulnerable since snow loads are expected to increase with higher levels of winter precipitation (NRTEE, 2009). Already in the Northwest Territories, 10% of public access buildings have been retrofitted since 2004 to address critical structural malfunctions. An additional 12% of buildings are on high alert for snow load-related roof collapse (Environment Canada, 2010). As permafrost continues to thaw, greater impacts will be linked to the increase in snow loads.

Adaptation Responses by Government and Community in Response to These Vulnerabilities

Government and community leaders have put emphasis on action and preparedness. The money required to relocate communities provides a strong deterrent for complacency. Where necessary, relocation will be utilized as a last resort. Though each tier tackles the issue from a different angle, their approaches are proving complementary. This section will explore adaptation efforts from each level of government and the contribution they make to adaptive capacity in Northern Canadian communities.

Federal level

The Canadian government contributes to adaptation efforts through provision of assistance after a disaster or in order to relocate structures. Also, consideration is being given to the incorporation of climate change into the 2015 version of the National Building Code (Auld, 2011) which would help ensure that future infrastructure is built to a more appropriate standard and that adaptive measures are incorporated into the design and building of any new infrastructure. This would also help ensure that adaptation measures are implemented in a uniform way across the country.

Another adaptation initiative that has come from the federal level is the site-selection guidelines developed by the Canadian Standards Association (Environment Canada, 2010). Though voluntary, this set of guidelines encourages engineers, land-use planners and developers to consider environmental factors including the rate of permafrost thaw and type of soil, when building. Additionally, it strongly encourages the use of projections and models in the site-selection process, instead of relying on extrapolated weather trends (Environment Canada, 2010).

Provincial/territorial level

The territorial governments are contributing to the protection of infrastructure in two main ways:

- Conducting and funding research to identify vulnerable areas and populations, as well as feasible adaptation strategies
- Implementing adaptation options such as thermosyphons in government run buildings.[2] There have been approximately 85 flat loop thermosyphon foundations constructed into Territorial-owned buildings including schools and hospitals, prisons and visitors centres in Nunavut, Northwest Territories and the Yukon (Holubec, 2008).

[INSERT FOOTNOTE 2: Thermosyphons work by allowing the base of a building to be placed directly on the ground (Environment Canada, 2010). They help prevent permafrost thaw through passive cooling.]

The installation of thermosyphon technology is not, in itself, a long-term strategy but merely prolongs the lifetime of most infrastructure, as they last for approximately 40 years depending on the speed of permafrost thaw (Environment Canada, 2010). In addition, though they can be used successfully to protect again permafrost thaw in buildings, they cannot protect other types of infrastructure (Environment Canada, 2010).

Municipal level

The municipal level is often the most involved in building adaptive capacity and implementing adaptation strategies because they are the closest to the damage caused by climate-related impacts. Municipalities, community groups and businesses all over the three Territories have contributed to this process in many ways. Some examples are:

- *Insulated lining* underneath a 100 metre section of runway to prevent damage from permafrost thaw – Yellowknife, NWT (Infrastructure Canada, 2006)
- *Wind deflection fins* to prevent snow loading on roofs and obstructions around exits- NWT (Waechter, 2005 - http://www.rwdi.com/cms/publications/16/t05.pdf)
- *Urban planning and design* to reduce exposure to wind and snowdrifts as well as minimize heat loss from buildings – Iqaluit, NU (NRCAN, 2010 - http://adaptation.nrcan.gc.ca/case/iqaluit_e.php)
- *Construction of new bridges and all-weather roads* to replace ice roads that are no longer stable – All three territories (Infrastructure Canada, 2006)
- *Use of shims or pillars* to elevate buildings making them less vulnerable to permafrost thaw – All three territories (USARC, 2003)
- *Concrete mats bound together with chains* to limit erosion – Tuktoyuktak NWT (Johnson et al., 2000)

Communities in Northern Canada need greater adaptive capacity to cope with climate-related impacts. Despite the complexity of such impacts however, a concerted effort from three tiers of government and community can work to reduce the vulnerability of infrastructure and Northern communities.

Nomadic Peoples and the Dzud

The Dzud, the Mongolian term that refers to unusually difficult winter conditions, is a long-lasting cold phenomenon that has disastrous implications for nomadic pastoralism. These events usually occur following a summer drought, and can result in the death of significant numbers of livestock and wild animals due to hunger, freezing and exhaustion [Marin 2008, 2010]. The Dzud also represents a high risk to the health and livelihoods of the herders, as well as the national economy. The Dzud is characterized by summer drought followed by a snowy autumn; extremely low temperatures in the winter, and drifting windstorms in the spring that prevent livestock from grazing (NAMHEM, JEMR 2000).

Dzud Event of 2009-10: Impacts, Preparedness, and Relief

In the summer of 2009, 60 percent of Mongolia suffered from drought conditions leaving the limited pasturelands overgrazed and restricting haymaking and foraging abilities of the residents. Drought is an important pre-condition of a Dzud since it means that animals and humans alike are unable to adequately prepare for the coming winter (Jigmiddorj, 2010). In this weakened state, they are more susceptible to disease and cold. In the winter of 2009-2010, 81 percent of country suffered from conditions of heavy snow storms and extreme cold. By February 2010 the northern part of Mongolia was 3.0-6.3ºC colder compared to climatic norms, 90 percent of the country was snow covered and 40 percent covered by 30-49 cm of snow (Jigmiddroj, 2010).

About 57 percent of all country herders' households and their livestock were affected by Dzud (Batbold, 2010). About 8.1 million heads of livestock were lost and by end of April, 2010, 8,711 households had lost all their animals, 32,756 households had lost more than half of their animals, and more than 1,400 households had migrated from rural area to towns in order to seek work (Batbold, 2010). In order to survive the impacts of the severe winter and drought, many herders were forced to take loans from commercial banks such that nearly 41% of the 170,000 herders' households ended up in debt equivalent to $US45M (Batbold 2010).

Additionally, the equivalent of $US18.7M was spent for aid and relief activities by the government for animal fodder, transportation, herders' medical and social services, disposing of animal carrions to prevent outbreaks of disease, and rehabilitation of roads and mountain passes blocked by snow (Batbold 2010). The 2010 annual livestock census accounted one forth of Mongolia livestock losses from this Dzud event (NSO 2010).

Recent History of Dzud

The Dzud of 2009-10 was one of several recent events. In 1999-2000, the Dzud covered 70% of the country and caused serious damage to animal husbandry (NAMHEM, JEMR, 2000). It was especially devastating because livestock were already lean from the previous winter Dzud and had little chance to recover to withstand the harsh climate. A substantial number of livestock perished from starvation and exhaustion as well as from cold. To compound the problems, the movement of animals to better pasture was done improperly resulting in trampling of pasture.

After 3 consecutive years of dzud 2000-2002, 12,000 herders' families had lost all of their livestock, and thousands of families were subsisting below the poverty line. Mongolia's gross agricultural output in 2003 had decreased by 40% compared to that in 1999 and its contribution to the national gross domestic product (GDP) decreased from 38% to 20% (Dzud Impact 2004, AIACC, 2006). Nationally, Mongolia had lost nearly one third of its livestock, including half of cattle and 37% of horses. The 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 (JEMR 2004).

In addition to the effects of the Dzud on cattle, the cold climate had dangerous impacts on the residents in the region. Given that the food supply was so low (with animals dying off and cropland unable to support food production), the Mongolian people suffered from lack of food. The poverty and unemployment related to the loss of the herder's livelihood meant that healthcare was unavailable to a greater proportion of the population. Finally, in response to the harsh climate changes, a growing proportion of the resident population migrated (NAMHEM, JEMR 2000; AIACC AS06, 2006; NCRMSAP 2009, MARCC 2009).

Projections of Future Dzud

Climate-change models project increases in air temperature of around 4.7°C and winter precipitation by from 4 to 10%. This combination unfortunately indicates an expected increase of both drought conditions in the summer and storms in the spring, fall and winter months. Additionally, this type of change could contribute to a shifting of natural zones, increase of desert area and decrease of steppe and forest area, leaving around 70% of the country in desert conditions (MARCC 2009).

Efforts to Mitigate and Reduce Dzud Losses

The experience of increased Dzuds in recent years has produced lessons learned from the experience and recommendations to reduce risk from these events. These tools have guided the national and local governments, professional organizations, herders, and donor and aid organizations and urged them to take the practical measures towards implementation of adaptation strategies. The following section will discuss contributions at the local, nation and international levels.

National level

The recent national climate change assessment report set government strategy priorities for implementation of the adaptation measures in agriculture and water resource sectors: (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. Additionally, the benefits of adaptation measures are not immediately observable. These factors make it difficult to 'sell' adaptation funding to the public [MARCC 2009].

Local level

The NCRMSAP [2009] considers the importance of practical actions at the local level that address the needs of those most affected by climate change; in particular women, the elderly and children. It further sets 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 following:

- 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

These approaches require collaboration from public and private sectors, herder groups, members of civil society and local government (Ykhanbai et., al., 2004), herders participatory early warning system with use of modern communication technology (Oyun, 2005, Togtokh, 2011, Wang Xiaoli, Ronnie Vernooy, 2011).

International level

International level assistances aim 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 Dzud and strengthening the post-disaster response system. For instance, in winter 2010 the World Bank has mobilized 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 that includes 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; and 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 (Arshad Sayed, 2010).

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Case Study 9.2.7. Disastrous Epidemic Disease: The Case of Cholera

<u>Background</u>

Weather has a wide range of health impacts and plays a role in the ecology of many infectious diseases. The overall relationship between weather and disease is complex and often indirect, as the case of cholera illustrates.

Weather and Health

Weather and disease have a complex relationship. As is the case with other impacts explored in this report, not all extreme health impacts associated with weather necessarily result from extreme weather events. While severe weather often has significant public health impacts (Noji 2000), some severe health impacts result from less dramatic weather events. These impacts are typically indirect, as opposed to the direct health impacts of severe weather, e.g. traumatic injuries associated with storms that are direct results of exposure to kinetic energy, and are mediated by a constellation of factors. Underdeveloped health and other infrastructure, poverty, and political instability interact with severe weather to worsen health impacts, sometimes to a disastrous degree. Cholera provides a clear example of a climate-sensitive disease, largely perpetuated by poverty and associated factors, that may become more widespread and as the climate continues to change. In addition to shifting ecological conditions to favour increased cholera exposure, climatic shifts may introduce new stresses that increase cholera prevalence and widen its geographic range. Poverty reduction and improvements in engineering, critical infrastructure, and political stability and transparency can interrupt this chain of events, increasing resilience to extreme health impacts from such climate sensitive disease.

Background: Cholera's Human Ecology

Cholera has a very long history as a human scourge. The world is 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 annual global burden of disease is estimated at 3–5 million cases and 100,000–130,000 deaths (Zuckerman, Rombo et al. 2007; World Health Organization 2010). Primarily driven by poor sanitation, cholera cases are concentrated in areas burdened by poverty, inadequate sanitation, and poor governance. Between 1995-2005, the heaviest burden was in Africa, where poverty, water source contamination, heavy rainfall and floods, and population displacement were the primary risk factors (Griffith, Kelly-Hope et al. 2006).

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). Weather, particularly seasonal rains, has long been recognized as a risk factor for cholera epidemics. Cholera is one of a handful of diseases whose incidence has been directly associated with climate variability and long-term climate change (Rodó, Pascual et al. 2002). One driver of cholera's presence and pathogenicity is the El Niño Southern Oscillation (ENSO), which brings higher temperatures, more intense precipitation, and enhanced cholera transmission. ENSO 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). There is concern that climate change will work synergistically with poverty and poor sanitation to increase cholera risk.

The Risk of Disastrous Cholera Epidemics

As with other disasters, the risk of disastrous cholera epidemics associated with weather events can be decomposed into hazard probability and population vulnerability, which can be further broken down into exposure probability, population susceptibility, and adaptive capacity. Here we focus on factors affecting vulnerability.

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). In coastal regions, there is 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, 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, affect exposure probability (Huq, Sack et al. 2005). Many of these factors appear to be similar across regions, although their relative importance varies, 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). For example, marine and estuarine sources were the source of the pathogenic *V. cholerae* strains responsible for cholera epidemics in Mexico in recent El Niño years (Lizarraga-Partida, Mendez-Gomez et al. 2009).

Other variables associated with increased exposure likelihood, including conflict (Bompangue, Giraudoux et al. 2009), population displacement, crowding (Shultz, Omollo et al. 2009), and political instability (Shikanga, Mutonga et al. 2009). 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.

Population Susceptibility

Population susceptibility includes both physiological factors that increase the likelihood of infection after cholera exposure, as well as social and structural factors that drive the likelihood of a severe, persistent epidemic once exposure has occurred. Physiologic factors that affect cholera risk or severity include malnutrition and co-infection with intestinal parasites (Harris, Podolsky et al. 2009) or the bacterium *Helicobacter Pylori*. 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 a significant impact on population vulnerability to cholera over long periods (Koelle, Rodo et al. 2005).
While physiologic susceptibility is important, social and economic drivers of population susceptibility persistently seem to drive epidemic risk. Poverty is a strong predictor of risk on a population basis (Ackers, Quick et al. 1998; Talavera and Perez 2009), and political factors, as illustrated by the Zimbabwe epidemic, are often very important drivers of epidemic severity and persistence once exposure occurs. Many recent severe epidemics exhibit population susceptibility dynamics similar to Zimbabwe, including in other poor communities (Hashizume, Wagatsuma et al. 2008), in the aftermath of political unrest (Shikanga, Mutonga et al. 2009), and following population displacement (Bompangue, Giraudoux et al. 2009).

Adaptive Capacity

Cholera outbreaks are familiar sequelae of complex emergencies. The disaster risk management (DRM) community has much experience with prevention efforts to reduce the likelihood of cholera epidemics, containing them once they occur, and reducing the associated morbidity and mortality among the infected. Best practices include guidelines for water treatment and sanitation and for population-based surveillance (The Sphere Project 2004).

The 2008 Zimbabwe Cholera Outbreak

Zimbabwe has had cholera outbreaks every year since 1998, with the 2008 epidemic 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 onset of seasonal rains, in Chitungwiza city, just south of the capital Harare (World Health Organization 2008). In the initial stages, several districts were affected. In October, the epidemic exploded in Harare's Budiriro suburb and soon spread to include much of the country, persisting well into June 2009, and ultimately seeding outbreaks in several other countries (see Figure 9-3). 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 (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) ranging from 4-5% (Mason 2009) (see Figure 9-4). Most outbreaks have CFRs below 1% (Alajo, Nakavuma et al. 2006). Underlying structural vulnerability was also central: 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 9-3 HERE:
Figure 9-3: Regional spread of the 2008 Zimbabwe epidemic.]

[INSERT FIGURE 9-4 HERE:
Figure 9-4: Case fatality rates for Zimbabwe by district.]

Disease Risk Management

There are several risk management considerations for preventing cholera outbreaks and minimizing the likelihood that an outbreak becomes a disastrous epidemic. Public health has a wide range of interventions for preventing and containing outbreaks, and several other potentially effective interventions are in development. As is the case in managing all climate-sensitive risks, the role of institutional learning is becoming ever more important in reducing the risk of cholera and other epidemic disease as the climate shifts.

Conventional Public Health Strategies

The conventional public health strategies for reducing cholera risk are: 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).

Newer Developments

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.

The Role of Learning

Managing disease risk, like other risk management processes, will necessarily become more iterative and adaptive as climate change introduces greater variability into familiar systems. Learning is an important component of this iterative process (see Chapter 1).

There are multiple opportunities for learning to enhance risk management related to epidemic disease. First, while reactive containment processes can be essential for identifying and containing outbreaks, this approach often glosses over root causes in an 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). Without losing the focus on containment, institutional learning could incorporate strategies to address root causes, reducing the likelihood of future outbreaks. This includes continued efforts to better understand cholera’s human ecology to explore deeper assumptions, structures, and policy decisions that shape how risks are constructed. In the case of cholera, such exploration has 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.

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Case Study 9.2.8. Cities Climate Change Response: Coastal Mega-Cities Vulnerability

Introduction

Cities are one of the major 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. [UN HABITAT, 2008] Cities cover less than 1% of the earth's surface, but are home to around 50% of the world's population (WWF, 2009). At the same time, cities, and especially the urban poor in the developing world, are particularly vulnerable to natural disasters such as storms, floods, heat waves, and earthquakes, and man-made air pollution and waste [UEPB 2009].

Many mega-cities are situated in low-lying coastal or river-delta regions (e.g., Adelekan, 2006). Already stressed by rapid population growth and economic, social, health and cultural difficulties, developing coastal mega-cities are now increasingly vulnerable due to climate change, which has heightened the risk of disasters to cities and neighboring regions. High waves and storm surges can erode shorelines, damage dykes, and flood coastal communities, rice paddies, and aquaculture facilities. The impacts of other extreme events on coastal zones, like tropical cyclones (typhoons or hurricanes), are expected to increase due to sea level rise and changes in weather intensity—larger peak winds, heavier precipitation, and greater frequency—associated with climate change. A recent OECD report ranked global mega-cities (Nicholls et al., 2008) in terms of population and disaster vulnerabilities. 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 IPCC Synthesis Report (2007) considered that mangroves, salt marshes and coral reef ecosystems are *likely* to be especially affected by climate change.

Climate-change vulnerabilities of cities and settlement are mainly related to extreme weather events rather than to gradual climate change (very high confidence). Changes in current and projected climate change in extremes like tropical storms, storm surge, extreme rainfall, riverine floods, heat and cold waves and drought could impact the cities and settlements (Willbank et al, 2007)

Background

People living in slums and including those without adequate urban infrastructure are particularly vulnerable and will be among those that suffer the most from the adverse effects of climate change. Rising temperatures coincide with increased energy use for cooling. The loss of green cover in cities, in the form of parks, trees and agricultural land, raises urban temperatures, and also contributes to climate change [UEPB 2009]. However, some steps are being taken to adapt urban planning to environmental change. In China, for example, as of 2009, 40 eco-cities were in development (4 smart-grid pilot cities, 21 LED-street-light cities, 13 electric-vehicle cities). Cities vary in size, economic capacity, geographic location, and access to resources within the country and 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].

A common theme in the Copenhagen Diagnosis (2009) is that changes are happening more rapidly than earlier predictions accounted for, so that a risk management approach will be necessary in planning adaptation strategies for coastal cities. Adaptation strategies for the most vulnerable urban areas need to be a priority (Schipper and Burton, 2009). There is also a need to build human resource capacity to deal with climate-related hazards (McBean and Rodgers, 2010), combined with disaster risk reduction approaches.

Vulnerability of Cities to Climate Change

Cities in Megadeltas

Vulnerabilities to extreme weather events in megadeltas in a context of multiple stresses: the case of Hurricane Katrina. The development in some densely populated megadeltas of the world will be challenged by climate change depending on the adoption of appropriate adaptation measures. The experience of the U.S. Gulf Coast with Hurricane Katrina in 2005 is considered a good example of the impact of a tropical cyclone – of an intensity expected to become more common with climate change – on the demographic, social, and economic processes and stresses of a major city located in a megadelta. In 2005, the city of New Orleans had a population of about half a million, located on the delta of the Mississippi River along the U.S. Gulf Coast. The city is subject not only to seasonal storms but also to land subsidence at an average rate of 6 mm/yr rising to 10-15 mm/year or more. Embanking the main river channel has led to a reduction in sedimentation leading to the loss of coastal wetlands that tend to reduce storm surge flood heights, while urban development throughout the 20th century has significantly increased land use and settlement in areas vulnerable to flooding. A number of studies of the protective levee system had indicated growing vulnerabilities to flooding, but actions were not taken to improve protection Willbanks et al (2007)

Climate Change and Adaptation in Asian Coastal Cities

The World Bank, ADB and JICA funded case studies for Asian coastal cities such as Bangkok, Ho Chi Minh City, Kolkata and Manila which are at risk due to flooding. The cities have been examined by the A1FI and the B1 scenarios as likely high-low cases and the outputs showed i) increase factors such as mean temperature, precipitable water, extreme 24-hour precipitation, and seasonal mean precipitation; ii) robust linear relationship between the local temperature increase and the global mean temperature increase; iii) precipitable water in the four megacity areas increases at a rate of ~ 8%/^{0}K or larger. iv) For return periods larger than about 10 years, the IPCC models projected extreme 24-hr precipitation change ranges from ~ 3%/^{0}K to ~ 28 %/^{0}K; and concluded that the uncertainty in precipitation extremes is much larger than in temperature or precipitable water (Masahiro, 2008).

Climate change risk and vulnerability of cities are different. For instance, the economic damage of flooding in Bangkok is projected to rise roughly four-fold in 2050, and 70% of this cost would be attributed to land subsidence alone. About one million inhabitants of Bangkok and Samut Prakarn will be affected, and one in eight of the affected inhabitants will be from the condensed housing areas where most live below the poverty level. The Bangkok city lies in the Chao Phraya River Basin and has tropical monsoon climate with 1,130 mm average annual precipitation varying from 1,000 mm to 1,600 mm. Here flooding is driven by high seasonal rainfall events over 2 to 3 months. Recent floods have occurred in 2002 and 2006 (Masahiro, 2008).

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; and a concerted “hardening up” of infrastructure, including storm-drainage systems, water supply and treatment plants, protection or relocation of solid waste management facilities, and 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 such as the Thames barrier in the UK (Lavery and Donovan 2005) 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). The adaptation options developed for the Asian megacities include both structural and non structural measures (see Table 9-4) (Masahiro, 2008).

[INSERT TABLE 9-4 HERE:
Table 9-4: Example of adaptation options (Masahiro, 2008).]

Coastal defences have traditionally relied on "hard defence" structures such as sea walls, dykes and tidal barriers. Those adaptation strategies dependent on engineering and technology can have significant economic costs 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 damage salt marshes. Coastal protection adaptation strategies range from 'hard defence' to 'soft defence' such as natural resources management (Adger *et al* 2007). 'Hard defence' are manmade coastal structures used to reflect large amounts of wave energy and hence protect the coastline and soft engineering defence 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 defences need to be integrated to facilitate adequate adaptation. Biological diversity can play an important role in the soft coastal defence solutions. The Convention on Biological Diversity (2009) states that 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 the hard approach (e.g. intrusive coastal development, alternation, imposed land use practices) while empowering a soft approach wherever appropriate.

Cities are attempting to address a broad set of issues including the provision of basic urban services, road construction, managing urban growth, open spaces, coastal protection and other environmental objectives [UEPB 2009]. These initiatives illustrate 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 international level exchanges with the global Sustainable Urban Development Network (SUD-Net) and the Cities in Climate Change Initiative (CCCI).

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; 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. [World Resources 1996-97].

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 livable cities; and organized the first World Congress on Resilient Cities, bringing together multiple 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.

The UNEP and UN HABITAT Sustainable City Programme (SCP/LA21) 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 – locally, nationally, regionally, and globally. In addition, through the Cities in Climate Change Initiative (CCCI), conducted a joint assessment of city vulnerability to climate change, using systematic and structured methods and a broad participatory approach. After early pilot assessments in 4 cities such as Sorosogon (Philippine), Maputo (Mozambique), Kampala (Uganda), and Esmeraldas (Ecuador) the initiative was expanded for other cities of developing and least developed countries (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, grassroots networks, the private sector and national authorities. (UN ISDR, 2010)

Conclusions

Coastal mega cities are one of the major drivers of climate change but at the same time are the worst victims of the climate change impacts. People living with un-adapted and inadequate infrastructure and housing are at most risk, constituting a significant percentage of the urban population. Without targeted adaptation, the impacts will however be felt indiscriminately in both developed and poor countries and will hinder the road to sustainable development. In coastal megacities, the adaptation could be integrated and extended to cover coastal zone and/or the flood plain. In the face of a dwindling resource base, growing demand/use for resources, and increasing environmental extremes, 'soft coastal defense' should be encouraged and promoted whilst possibly considering reducing investment in 'hard defense' structures where appropriate (Campbell *et al*, 2009). The biodiversity based adaptation measures coupled with "mixed defenses" are receiving increased attention in 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 Developed Countries (LDCs).

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Case Study 9.2.9. Small Islands Developing States and Least Developed Countries: The Limits of Adaptation

Introduction

Small Island Developing States (SIDS) are small island and low-lying coastal countries that share similar development challenges, including small but growing populations, lack of resources (e.g. freshwater, land, soils), economic dependence on international markets, and high susceptibility to natural disasters (SIDSNET). SIDS are therefore among the most vulnerable states to the impacts of climate change and particularly to both natural and man-made environmental disasters, as they have a limited capacity to respond to and recover from such disasters.

Since 1971, the United Nations has designated a category of States as 'Least Developed Countries' (LDCs), including those that are deemed highly disadvantaged in their development process (many of them for geographical reasons), and more than other countries face the risk of failing to come out of poverty. As such, the LDCs are considered to be in need of the highest degree of attention on the part of the international community.

Around 25% of the LDCs are the SIDS and the LDCs and the SIDS share several characteristics: high levels of poverty, serious environmental degradation, and low human and institutional capacities for integrated and sustainable land management.

Vulnerabilities of SIDS and LDCs

Many SIDS face specific disadvantages associated with their small size, insularity, remoteness and proneness to natural hazards. SIDS are particularly vulnerable to the physical impacts of climate change, especially the increased frequency and intensity of droughts, floods, and hurricanes (Read, ICTSD 2010). 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 hinder their socio-economic development. In addition, the hazards of extreme weather events are coupled with other long-term climate change impacts, especially sea-level rise. 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, changes in disease patterns, economic losses and population displacement, all of which reinforces their increased vulnerability to extreme weather events (Nurse and Sem, 2001), (Pernetta J.C., 1990). SIDS are also home to many diverse and local minority communities who depend on ecosystem services that are negatively impacted by extreme weather events.

Within the LDCs, 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). 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).

Examples of Impacts on the Vulnerable System of SIDS and LDCs, and Measures Taken to Reduce Vulnerability

Mahe Island, Seychelles

In January 2004, torrential rains brought about a serious flood in Au Cap District on Mahe Island in Seychelles. The heavy rains caused extensive damages to properties and other infrastructure, agriculture, and business. The President of the Republic put together a task force to study the problem and analyze 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, and that long-term disaster resilience will require a much broader set of initiatives, including setting up early warning systems, updating emergency management plans, a maintenance programme for drainage systems, and capacity-building in emergency management and technical fields such as hydrology and flood forecasting. The findings of the task force indicate that SIDS must take seriously the need for resilience-building and technical capacity strengthening, which for many states requires best-practices and information-sharing networks with countries with more expertise. The flooding, a stark example of an extreme weather event, has created an awareness in Seychelles regarding these capacity-building needs (UN DESA, Code 57).

Republic of the Marshall Islands

Fresh water availability is a major concern for many SIDS, like the Republic of the Marshall Islands (RMI). And because SIDS are especially vulnerable to extreme weather events, their water supplies face the challenges of rapid salinization due to seawater intrusion and contamination. The Marshall Islands, for example, lack the financial and technical resources to implement seawater desalination for their population, impeding the efficient sustainable recovery of freshwater from groundwater and increasing their susceptibility to extreme climate change events. Because simple abstraction of freshwater from thin groundwater lenses, a typical practice 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 in RMI. Therefore, 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 proved to be of great help against saltwater contamination of fresh groundwater 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. RMI has benefited from its use of new, pioneering technology to limit the effects of extreme weather events on its water supply, and from its partnerships with leading international bodies to devise and implement complex technological projects (UN DESA, Code 326).

The Maldives

The Maldives consists of 1,192 islands, at least 80 percent of which are 1 meter or less above sea level, and only three of which have a surface area of more than 500 hectares. These characteristics make them highly vulnerable to sea level rise and extreme weather 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. Such devastation in a SIDS might be countered with further disaster preparation and efforts to maintain emergency funds to rebuild their economies (De Comarmond and Payet, 2010).

Malawi

Malawi 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).

Ethiopia

Since 2004, the Government of Ethiopia 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).

Grenada

Grenada is a small tri-island state in the Eastern Caribbean with a population of 102,000, of which 9,000 live on the two sister islands of Carriacou and Petite Martinique, and a per capita gross national product of US$7,959. It is a small open economy that is vulnerable to external shocks and natural disasters as seen by the effects of 9/11, Hurricane Ivan, which devastated the economy in 2004, and Hurricane Emily, which struck in 2005. Hurricane Ivan brought major disruption to an economic recovery process, and Hurricane Emily followed 10 months later, virtually completing the trail of destruction started by Ivan. The hurricanes impacted on every sector of the economy and society with devastating force. In both the economic and social sectors, the capital stock was severely damaged bringing the overwhelming majority of income, employment, and foreign exchange activities to a halt. Assessment of the damages from Hurricanes Ivan and Emily by Grenada's Agency for Reconstruction and Development and the Ministry of Finance was set at US$1.2 billion, representing over 250% of the country's GDP (UNDP, CPAP 2006-2009).

Policy and Management Practices

The importance of disaster risk-reduction strategies is apparent. It is necessary to move from post-disaster reactions to building capacity for prevention. Many SIDS examined tended to suffer worse disasters when they lacked early warning systems. Early warning and information systems at regional and sub-regional levels are appropriate. Such systems, however, depend on functioning and accurate regional climate observation systems, which also need to be established among SIDS and other stakeholders. Further expanding international cooperation for the development of early warning and information systems within the context of broader disaster prevention efforts might need to be sensitive enough to meet the needs of small states, especially the SIDS (UN, 2005).

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 filtering down to local levels may facilitate vulnerable communities obtaining the means to mitigate for disasters. Therefore these policies should be culturally and gender sensitive and could be considered for 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. Development plans and poverty reduction strategies in SIDS, including disaster risk assessment as an integral component, could be considered as sensible precautions by Member States and international organizations. This could help to ensure that their investments to reduce risk and vulnerability of development gains are not lost. For disaster risk reduction to be strengthened in SIDS both a humanitarian and a development responsibility in line with the Millennium Development Goals would be beneficial. Member States could be encouraged to support the process of consolidation of ISDR in SIDS as a valuable instrument for sustainable development (UNISDR, 2004).

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. 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. Many SIDS can benefit from such international scientific collaboration to improve their disaster resilience and understanding of potential threats (UN DESA, Code 58).

Although climate change-specific policies seem 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 support mainstream adaptation to climate change remains limited, particularly in the least developed countries. National policy making in this context remains a major challenge. This might be best met with appropriate 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).

Lessons Identified

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).

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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Case Study 9.2.10. Risk Transfer: The Role of Insurance and Other Economic Approaches to Risk Sharing

<u>Introduction</u>

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.

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.

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 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.

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 (see Table 9-5). 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

[INSERT TABLE 9-5 HERE:
Table 9-5: Examples of mechanisms for managing risks at different scales (Linnerooth-Bayer and Mechler, 2009)**.**]

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. 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.

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.

<u>Analysis of Information Available on the Role of Thematic Approach in Specific Cases</u>

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.

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.

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.

Index-Based Insurance in Bolivia

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. 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).

<u>Role of Disaster Risk Reduction and Climate Change Adaptation Related Activities</u>

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.

Learning and Lessons Identified

The current experience in developing countries of the benefits of insurance for 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 9.2.11. Promoting Disaster Risk Reduction and Adaptation through Education, Training, and Public Awareness

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 illustrates practices in primary school education, training programmes and awareness-raising campaigns in various countries.

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",[3] furthered and raised awareness of the importance of the education agenda across some countries (ISDR 2009). Furthermore, the United Nations Decade of Education for Sustainable Development 2005-2014 calls for improving the knowledge base on disaster prevention and reduction as one of the keys to sustainable development.

[INSERT FOOTNOTE 3: 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]

To personalize information and elicit behavioural change, risk reduction programmes not only impart knowledge of the natural hazards but also engage students in identifying and reducing risk in their surroundings. Disaster education should not be confined within the school but could be beneficially promoted to be shared with families and communities (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, that 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.

Integrating Disaster Risk Reduction and Climate Change in the Curriculum (Philippines)

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 (Luna *et al*. 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 (Luna *et al*. 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 (Luna *et al*. 2008).

Training for DRR and Adaptation

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).

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).

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).

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).

Raising Public Awareness

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.

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 2008c).

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 2008d).

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.* 2009, 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.* 2009, 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).

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).

<u>Lessons Identified in Effectively Communicating Risk Information</u>

Based on experience of public education campaigns for disaster risk reduction, some working axioms have been demonstrated (Bonifacio *et al*. 2010):

- It could be beneficial if people could understand who is at risk, the potential and likely physical, economic, communal and cultural heritage losses, within a specific timeframe.
- When people are clearly informed about what they can do to reduce their risks, before, during and after a disaster, they are capable of understanding and remembering the basics.
- 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.
- Most people are more motivated by positive examples than by fear.
- Culture is shaped by language, stories and traditions. Therefore, local knowledge can be used to transmit information.
- Children can be engaged in active, inquiry-oriented learning through exploration and play.
- Lectures, sermons and moral exhortations are not as effective as when people participate in a solution, when they believe it is their own idea.

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Case Study 9.2.12. Effective Legislation for Multilevel Governance of DRR and Adaptation

<u>Introduction</u>

The Philippines is at the forefront of a new trend to integrate climate change and disaster risk reduction legislation: not only does the new disaster risk reduction legislation address climate change, the Climate Change Law of 2009 addresses disaster risk reduction. The Philippines’ new measures are of relevance to other Governments as they assess whether their own national legislation to reduce and manage disaster risk is adequate for adapting to climate change. Through an analysis of benchmark DRR laws, such as those from South Africa and Colombia, this case study explores critical provisions for good legislation, identifying key elements that are essential to the success of both disaster risk reduction and adaptation. It emphasizes useful measures for governance at various levels: from regional to national, as in the case of the European Commission directive, and from national to local levels, as exemplified by Spain and France. The elements identified can serve as a model for climate change adaptation legislation or improve existing disaster risk management legislation.

Background: What Constitutes Good Legislation for Disaster Risk Reduction and Adaptation?

A legal framework establishes policies, practices and processes for reducing and managing risk, as well as penalties and incentives for their implementation. It also assigns responsibility, empowers agencies and bodies, and assigns budget lines (Mattingly 2002; Pelling and Holloway 2006; Britton 2006). Because legislation promotes accountability and coordination, the Hyogo Framework for Action calls on Governments to adopt or modify legislation to reduce disaster risk (UNISDR 2005a). A majority of States have some form of disaster risk management legislation or are in the process of enacting it (UNISDR 2005b, UNDP 2007), but relatively few have enacted climate change legislation to date (United Kingdom, Canada, France and Philippines have specific climate change legislation).

Legislation alone does not guarantee effective implementation; however, laws that have proven effective for disaster risk reduction contain elements and provisions that can be replicated when developing or strengthening laws to adapt to climate change. One useful first step for potential climate change adaptation laws is to identify existing measures that have worked well within the State in reducing disaster risk so as to benefit from experience. Another useful measure is to assess whether a State's current DRR legislation is adequate for meeting the new challenges presented by climate change or whether a more comprehensive DRR law or a new climate change law would be most beneficial.

Elements of Effective Legislation

Some of the elements that effective DRR and adaptation laws have in common include the following:

- The law provides legal and policy coherence by explicitly linking to other laws and policies from relevant sectors and throughout all administrative levels.
- The law devolves both responsibility and funding from national to regional (and from national to local levels) with clarity about the generation of funds and procedures for accessing resources at every administrative level.
- The institutional arrangements the law establishes provide both access to power for facilitating implementation and opportunities to "mainstream" disaster risk reduction and adaptation into development plans.
- The law is based on comprehensive, up-to-date risk assessment that mandates periodic reassessment as risks evolve and knowledge of climate change impacts improves.
- The law includes provisions that increase accountability and enable coordination and implementation of disaster risk reduction and adaptation—i.e., the clear identification of roles and responsibilities, requirement to establish and maintain a national risk database, mandate to provide public access to risk information, education and training, as well as enable access to participate in decision making.

The next section illustrates these principles with specific examples.

Linked Laws and Policies across Sectors and Levels

Some States successfully implement disaster risk reduction through a number of sectoral laws, such as Sweden[4] and Slovenia.[5] Others, such as Colombia, South Africa and the Philippines, develop one overarching, comprehensive legal framework for disaster risk reduction. Although both approaches can work for individual States, many high-income developed countries reported that a challenge to reducing risk is the lack of an overarching national policy and legal framework to facilitate a holistic approach (ISDR 2009). An overarching framework can generate cost-effective policies that balance a multitude of sometimes contradictory laws and decrees, such as 20,000 legal acts in Kyrgyzstan (UNDP 2007), or Indonesia's 120 different pieces of disaster risk management related legislation (UNDP 2009).[6]

[INSERT FOOTNOTE 4: For example, 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 5: For example, 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 6: The latter was addressed in the 2007 Disaster Management Bill that aims to provide leadership for comprehensive disaster risk reduction (UNDP ILS Indonesia 2009).]

Regional legislation, such as the European Commission's (EC) Floods Directive (2007) and Water Framework Directive (2000), both described in subsection 2 below, can also foster legislative coherence on a specific issue. The EC's Floods Directive is specifically linked to the pre-existing Water Framework Directive and includes flood risk reduction of shared river basins. At the national and sub-national level, implementation of these directives has facilitated EU members states' efforts to address simultaneously multiple processes that impact drought and flood risk, including agricultural policies and integrated water resource management, and land use (EC, 2000; EC, 2009). France, for example, created its Grenelle of the Environment with legislation that brings multiple competing stakeholder groups together to develop policies that can reduce flood and risks in a coherent manner (Deboudt, 2010; France, 2010).

South Africa and Colombia: the comprehensive legislation model

In South Africa, the 2002 Disaster Management Act provides a comprehensive framework for disaster risk reduction implementation at all levels. It defines the hierarchical institutional structure that governs disaster risk management in the country, 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 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. Colombia has also enacted dozens of sector-specific laws, in particular environment, land use, housing and urban development, and education, among others, that govern and support disaster risk reduction (Vásquez 2006, Colombia Ministerio 2009).

The Philippines: the linked legislation model

The Philippines Climate Change Act was enacted in 2009 and innovates by closely linking climate change and disaster risk. At the outset, it adopts the UNFCCC's ultimate objective of stabilizing greenhouse gas emissions and the Hyogo Framework for Action's "strategic goals in order to build national and local resilience to climate related disasters." In recognizing that "climate change and disaster risk reduction are closely interrelated and [that] 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). The Philippines Disaster Risk Reduction and Management (DRRM) Act, enacted in 2010, conversely includes several references to climate change (Act 10121, Sec 2 (a), (d), (e), (g)).

The linkage between DRR and climate change processes in the Philippines is likely to be facilitated by both laws' references to each other and their specific references to the other's process in their mandates. For example, like the Philippines' DRRM 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 the "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 are to "[e]nsure 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).

Devolution of Power and Funding

Because disasters and climate change impacts are experienced locally, adaptation 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 will involve 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 with the accompanying transfer of capacity and resources to newly accountable local actors, and parallel support could be beneficial for civil society organizations that hold local governments accountable and fill the void if those governments were to fail (Mitchell et al., 2008). The decentralization of disaster risk reduction and climate change adaptation, complemented with increased autonomy of local agencies and enhanced support of these actors from national governments and regional institutions, would have positive benefits (Baker and Refsgaard, 2007; Gopalakrishnan and Okada 2007). The following case illustrates the devolution of power from regional to national level.

Implementation of the European Commission's Water Framework Directive in Spain and its Floods Directive in France

The European Commission's Water Framework Directive (WFD) (2000) seeks to reduce the impacts of droughts and floods (EC, 2000, I(e)). The WFD's 2010-2012 work programme supports integrated implementation at multiple scales of government by identifying concrete deliverables at those scales (EC, 2009).

The WFD 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 subsidiarity 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 by a network of experts from the European Union. 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). To facilitate integrated implementation, the EU's Water Directors mandated that expert group identify ways to improve financing for improvements in water efficiency (EC, 2009).

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 a 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, civil society and the private sector, 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; and
- Clearly defined responsibilities for implementation (France 2003; France 2009; Deboudt, 2010).

Furthermore, the EC also evaluates whether flood risk management measures receive adequate funding (EC, 2009).

Other national level examples

At the national level, the Philippines Climate Change 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 1.1 million USD are allocated for the implementation of the Act.

Adequate funding is tightly linked to the ability to effect risk reduction and adaptation at all levels. UNDP (2007) characterises the provision of adequate funding as the ultimate "litmus test" of government commitment to disaster risk reduction. For example, in South Africa, eight years after the promulgation of the disaster risk reduction 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 costs related to start-up, continuous operations, disaster risk reduction projects, response recovery and rehabilitation activities, and training and capacity building programmes, which are specifically stipulated for funding in the Framework (NDMC 2009, Visser and Van Niekerk 2009; SACoGTA 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).

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 (Colombia 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, the actions of the National System for Attention and Prevention to Disasters are limited, and the Fund's resources are directed to emergency response rather than prevention (Cardona and Yamín 2007).

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).

The Philippines new DRRM law aims to redress this problem. It 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 (Philippines 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 (Philippines Act 10121, Sec 23). Unspent money will remain in the fund to promote risk reduction and disaster preparedness.

Institutional Arrangements for Access to Power and Integration into Sectors and Development Planning

South Africa's Intergovernmental Committee on Disaster Management is established by the president and reports to the president through Cabinet on response once a disaster has occurred (SANDMC 2007). In Colombia, the robust institutional structure for risk reduction was weakened through a series of reforms that have reduced the issue's standing in the hierarchy and diminished its political importance (although recently the president convened entities at all levels to motivate them to fulfill their disaster risk reduction mandates) (Colombia Ministerio 2009). Bolivia and Nicaragua give maximum authority to the national committee headed by the president and include representatives from the major ministries, the national department of planning, civil defence, the Red Cross Society and private sector members (UNDP 2007).

The positioning of DRR and climate change adaptation institutions within the highest levels of government has proven effective because this position often determines the amount of political authority of the national disaster risk management body (UNDP 2007, ISDR 2009). National disaster risk management offices attached to prime ministers' offices usually can take initiatives affecting 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).

Unfortunately, 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 is one of a handful of countries that have made a legal connection between disaster risk reduction and national development planning frameworks, and its DRR legislation requires that municipalities' Integrated Development Plans (IDPs) contain risk management plans.[7] This link is crucial because most climate-related disaster risk has been driven by poor development policies that have increased the exposure of assets—and people—to hazards (UNISDR, 2009).

[INSERT FOOTNOTE 7: 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 DRRM Act, sits within the Department of National Defense. To promote intersectoral integration, the DRRM Act mandates the inclusion of experts from all relevant fields as members of the Council (Philippines Act 10121, Sec. 5; Sec. 11(2)) and expressively defines its mandate on mainstreaming disaster risk reduction into sustainable development and poverty reduction strategies, policies, plans and budgets at all levels (Philippines Act 10121, Sec. 2). The Philippines Climate Change Act also addresses sectoral integration: "the policy of the State [is] to systematically integrate the concept of climate change in various phases of policy formulation, development plans, poverty reduction strategies and other development tools and techniques by all agencies and instrumentalities of the government" (Philippines Act 9729, Sec. 2).

Dynamic Assessment of Risk Knowledge

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). Therefore, effective legislation could address appropriate temporal scales and incorporate evolving information on climate change impacts and risks. Meanwhile, ensuring appropriate adaptive responses depends on this knowledge being generated, acted upon and evaluated continuously. For example, to support implementation of the WFD and Flood Directive, EC Water Directors created a Working Group on Floods (responsible for evaluating the implementation of the two directives with respect to climate change and in light of new risk maps, vulnerability assessments an flood risk assessments) and a Water Scarcity and Drought Expert Group that inputs into a Temporary Expert Group on Climate Change and Water (EC, 2009).

To ensure that legislation for disaster risk reduction and adaptation is dynamic and relevant, clauses about the periodicity of specific tasks mandated in the law can be included. For instance, the Philippines DRRM Act calls for the development of a framework to guide disaster risk reduction and management efforts to be reviewed "on a five-year interval, or as may be deemed necessary, in order to ensure its relevance to the times" (Philippines Act 10121, Sec 6 (a)). The Act also calls for the development of assessments on hazards and risks brought about by climate change (Philippines Act 10121, Sec 6 (j)). Likewise the Philippines Climate Change Act calls for the framework strategy that will guide climate change planning, research and development, extension and monitoring of activities to be reviewed every three years or as necessary (Philippines Act 9729, Sec 11). Similarly, the United Kingdom's Climate Change Act establishes the preparation of a report informing parliament on risks of current and predicted impact of climate change no later than five years after the previous report (United Kingdom Act 2008, Section 56 (1)).

Provisions for Coordination, Accountability, and Implementation

The attribution of roles and responsibilities is among the most critical functions of adaptation and disaster risk reduction legislation to ensure coordinated action and accountability. In addition to the clear hierarchies established by the legislations of South Africa, Colombia and Philippines, each entity in the hierarchy has been assigned concomitant responsibilities. Spain's application of the EC Water Framework Directive to reduce drought risk and France's flood risk reduction also define responsibilities clearly. These laws, such as France's Grenelle of the Environment, allow civil society and business also to play roles in reducing disaster risk and adapting to climate change. South Africa's, Colombia's and the Philippines' DRRM laws also include provisions for the involvement of NGOs, traditional leaders, volunteers, community members and the private sector in disaster risk reduction, and the Philippines' Climate Change Act establishes three seats for representatives from academia, business and nongovernmental organizations as well as four subnational representatives (Philippines Act 9729, Sec 5 (q-w)).

<u>Lessons Identified and Conclusion</u>

In addition to the five elements identified and illustrated above, several lessons emerge from this review to keep in mind when strengthening or developing legislation for disaster risk reduction and adaptation.

- *Need legislation for DRR and adaptation*: although policies and measures are critical to implementation, legislation promotes enforcement and accountability by codifying roles, responsibilities and expectations in a transparent manner that can be used to hold decision-makers to account.
- *Legislation takes a long time to develop; best to avoid starting from scratch*: it took decades to develop the DRR laws of South Africa, Colombia and Philippines, and Spain's National Drought Plan was the result of fifteen years of groundwork and planning, spurred on by the passage of the EC Water Framework Directive

(Spain 2001). Governments may be able to expedite the passage of effective legislation by taking stock of and then amending or building upon existing laws.

- *Political interest in climate change can be harnessed to improve national DRR law*. The UNFCCC Cancún Adaptation Framework formally recognizes DRR as an essential element of climate change adaptation and encourages governments to consider linking adaptation measures to the Hyogo Framework for Action (UNFCCC, 2010, Paragraph 14(e)). Governments may benefit by harnessing the political momentum to enhance their disaster risk governance capacities, and developing country governments can apply for adaptation financing to do so. Whether a State chooses to strengthen existing DRR law to support adaptation to climate change or develop new climate change law, it is critical to review the DRR law and its implementation for lessons.
- *When power and resources are decentralized, it is necessary to have knowledge and capacity at all levels* for implementation. The effectiveness of decentralized DRRM policies in Spain and France rely on strong institutional capacities at sub-national and local levels of government. Of equal importance, these measures have drawn upon people and institutions with decades of flood and drought risk management at the sub-national level.
- *International funding processes for adaptation will require a mechanism to ensure funds reach the local level*. Allocating finances for DRRM and adaptation measures has proven a challenge for many governments—even when they have enacted legislation whose implementation demands specific funding. Establishing independent (or semi-autonomous) expert groups to evaluate aspects of implementation—including inadequate funding—seems to be working in the EU, but it remains to be seen whether a review alone will work equally well in developing countries where resources for DRRM are already constrained. The use of Green Climate Funds to implement DRRM and adaptation legislation may be one solution given that these funds will require international reporting measures.

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Case Study 9.2.13. Early Warning Systems: Adapting to Reduce Impacts

Early Warning Systems for Disaster Risk Reduction and Climate Change Adaptation

At least since the 1990s, there has been a significant upward trend in the annual number of natural disasters (Vos et al., 2010; Munich Re 2010; 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*." Floods and storms are the dominant factor in these disasters. 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[8] 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[9] 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 8: UNISDR Terminology on Disaster Risk Reduction, 2009: Available at http://www.unisdr.org]

[INSERT FOOTNOTE 9: 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[10], in part thanks to the role of early warning systems and associated preparedness and response systems"*.[11]

[INSERT FOOTNOTE 10: 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 11: 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 (brunet et al., 2010). 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. Early warning systems provide one possible adaptation option to minimise any deleterious consequences resulting from any projected exacerbation of natural severe extremes. Such systems also provide a mechanism to increase public knowledge and awareness of natural risks, and may foster improved policy and decision making at various levels. 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.

Examples of Benefits of Early Warning Systems

Predictions of hazardous events can contribute to disaster risk reduction and sustainable development (McBean, 2007; 2009). 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). Assessments of adaptive capacity to responding to cyclone warnings have been done for India (Sharma et al., 2009), Florida (Smith and McCarty, 2009), New Orleans (Burnside et al., 2007), New South Wales, Australia (Cretikos et al., 2008) and China (Wang et al., 2008). Predictions of land-fall for tropical cyclones are very important (Davis et al., 2008). As presented in Case Study on 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. One of the issues is providing warnings in order that people can evacuate (Paul and Dutt, 2010; Stein et al., 2010). If forecasts are often incorrect, the response of people is affected (Dow and Cutter, 1998). Public health impacts due to hazards also depend on the preparedness of the local community (Vogt and Guha Sapir, 2009) and this can be assisted by early warnings. 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). Heat-health warnings have also been effective (Hajat et., 2010; Rubio et al., 2010; Michelozzi et al., 2010; Fouillet et al., 2008) although improvements are still needed. There are also social impacts of warning systems (Kalkstein and Sheridan, 2007)

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., 2008; 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.

<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).

Learning and Lessons Identified

Early warning systems directly contribute to climate change adaptation and disaster risk reduction. 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 effectively preparing for, responding to, and recovering from extreme events and disasters require understanding current and projected risks. Effective disaster risk management in a changing climate is facilitated by anticipatory strategies within and between sectors, with strong co-ordination and realizing adaptation potentials requires anticipation of vulnerabilities and anticipatory actions.

It is recognized that vulnerability, exposure and hence risk can never be reduced to zero, but it can be reduced and managed but effective early warning systems on short and longer timescales will convince disaster risk managers on appropriate actions. By incorporating longer-term early warning systems into disaster risk management, improved current risk management can facilitate adaptation to climate change. It is important to recognize that managing the rising uncertainty of a changing climate requires anticipatory action and early warning systems can contribute to that and climate-smart disaster risk management.

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9.3. Synthesis of Lessons Identified 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 this whole report. 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 changing climate.

In the case studies several recurring themes and lessons occurred and they should be highlighted for use by policymakers. One lesson is to invest in knowledge. In the case studies that dealt with cyclones, 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 incliding early warnings. Clearer understanding of health impacts and the benefits of safer hospitals and health care facilities are another important issue. In all cases, the point was made that with greater information available it would be possible to know the risks better and ensure that 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 applications.

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. A greater investment in proactive hazard and vulnerability reduction measures, as well as development of systemic and programmatic capacities to respond and recover from the events is needed, hence a risk management approach.

Another lesson is that, in order to implement a successful DRR or CCA strategy, legal and regulatory frameworks are beneficial in ensuring direction, coordination and effective use of funds. The case studies are helpful in this endeavour as effective implemented legislation has created a framework for governance of disaster risks. While this type of suggestion is mainly for national governments and how they devolve to local administrations, 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 maintain their usefulness. This cooperation could be at the local level through to 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, measures exist that could be taken to reduce the damage that is inflicted as a result of extreme events. The values in investment in increasing knowledge and warning systems, adaptation techniques and tools and preventative measures will cost money now, but may save money and lives in the future.

Table 9-1: Affected people and fatalities caused by tropical cyclones Bhola (1970), Gorky (1991), and Sidr (2007) in Bangladesh.

Cyclone event	Storm Surge	Maximum Wind Speed	Number of Affected Districts	Number of Affected People (approximate)	Mortality (approx.)
Bhola (1970)	6-9 m	223 km/h	5	1 mill.	300,000 – 500,000
Gorky (1991)	6-7.5 m	225 km/h	19	14 mill.	138,000
Sidr (2007)	5-6 m	Up to 245 km/h	30	8-10 mill.	4,200

Sources: Paul 2009, GoB 2008, Karim and Mimura 2008, CRED 2009.

Table 9-2: Improvements in key measures for reducing risk of tropical cyclones in Bangladesh since 1970.

Cyclone event	Cyclone shelters (Number)	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)	3,976	43,000	Storm Warning Centre equipped with modern technology and access to mobile phones in coastal regions.	1,500,000

Source: GoB 2008, ISDR 2009, Sommer and Mosley 1972,Paul 2009.
*(*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)*

Table 9-3: Characteristics of tropical cyclone Nargis (2008) in Myanmar.

Parameter	**Nargis 2008 (Myanmar)**
Max. wind speed	235 km/h
Storm surge	~4 m
Reported fatalities	138,000
People Exposed/Affected	2-8 millions

Sources: Webster 2008, PREVIEW 2009, CRED 2009.

Table 9-4: Example of adaptation options (Masahiro, 2008).

Climate change adaptation				
Climate change increases hazards	**Measures to Reduce Exposure**	**Measures to Reduce Vulnerability**	**Measures to Strengthened Capacity**	**Risk reduction**
Hydro-meteorological hazards increase Increases are expected in the variability and intensity of tropical cyclones, thunderstorms, hailstorms, tornados, blizzards, heavy snowfall, avalanches, coastal storm surges, floods (including flash floods), drought, heatwaves and cold spells. Hydro-meteorological conditions also can be a factor in other hazards such as landslides, wildland fires, locust plagues, epidemics, and in the transport and dispersal of toxic substances and volcanic eruption material. a/	**Retreat** 1. Retire and move critical infrastructure or housing that are in locations that become too hazardous **Restore natural buffers** 2. Mangroves buffer storm surge 3. Wetlands attenuate flood peaks 4. Reforestation retards runoff 5. Enhance infiltration in urban areas **Protect** • Flood embankments, polders, and sea walls, frequently combined with pumped drainage. • Increasing the hydraulic efficiency of the flood channel with dredging, widening and removal of obstructions; • Diverting the flood flows around the city through diversion channels; • Attenuating the flood flows upstream with reservoirs or through the managed flooding of the agricultural and wetland.	**Accommodate** • Flood proofing building exteriors • Placing lowest habitable or operable level of a house, building or factory above extreme flood elevation • Establishing cropping calendars and seed types that reflect flood/drought frequencies • Ensure critical public facilities are accessible and functional during floods/disasters • Major transport networks need to have elevations above extreme flood elevations • Power lines and transformers need to be above flood levels and high enough to allow clearance for rescue boats • Insulation of air-conditioned buildings lowers power costs and reduces GHG emissions	**Improved management** • Early warning systems • Land use planning and zoning • Building codes • Enforcement systems codes and zoning measures • Hazard mapping and public awareness campaigns • Review reservoir operation rules • Conduct dam safety assessments (including review of PMF) **Build resilience** • Community based disaster risk management plans and exercises • Evacuation plans and shelters • Meteorological forecasts	**Adaptation measures reduce risks/losses** • Climate change increases variability and intensity of hydro-meteorological hazards which increases risk • Risks are reduced when exposure and vulnerability are reduced, or if capacity is increased. • Climate change mitigation efforts reduce potential hazards and therefore risks.
	Structural measures: Any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard resistance and resilience in structures or systems. a/		**Non-structural measures:** Any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education. a/	

Table 9-5: 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

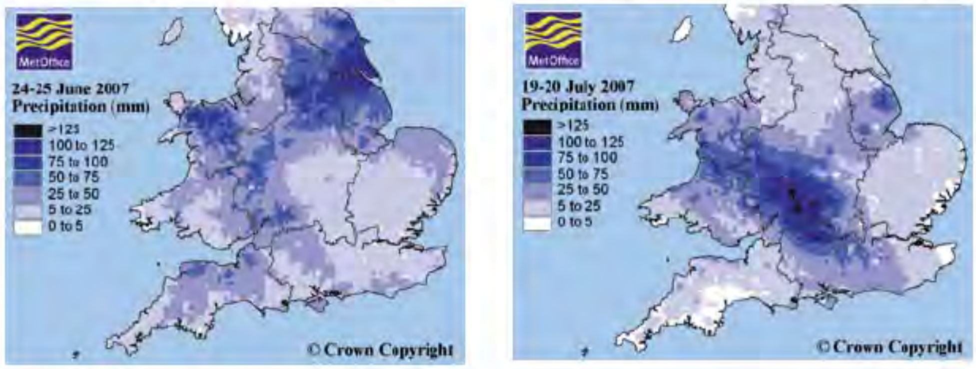

Figure 9-1: Precipitation levels for England and Wales during 24-25 June and 19-20 July 2007.

Figure 9-2: Canada's Permafrost Zones (NRTEE, 2009).

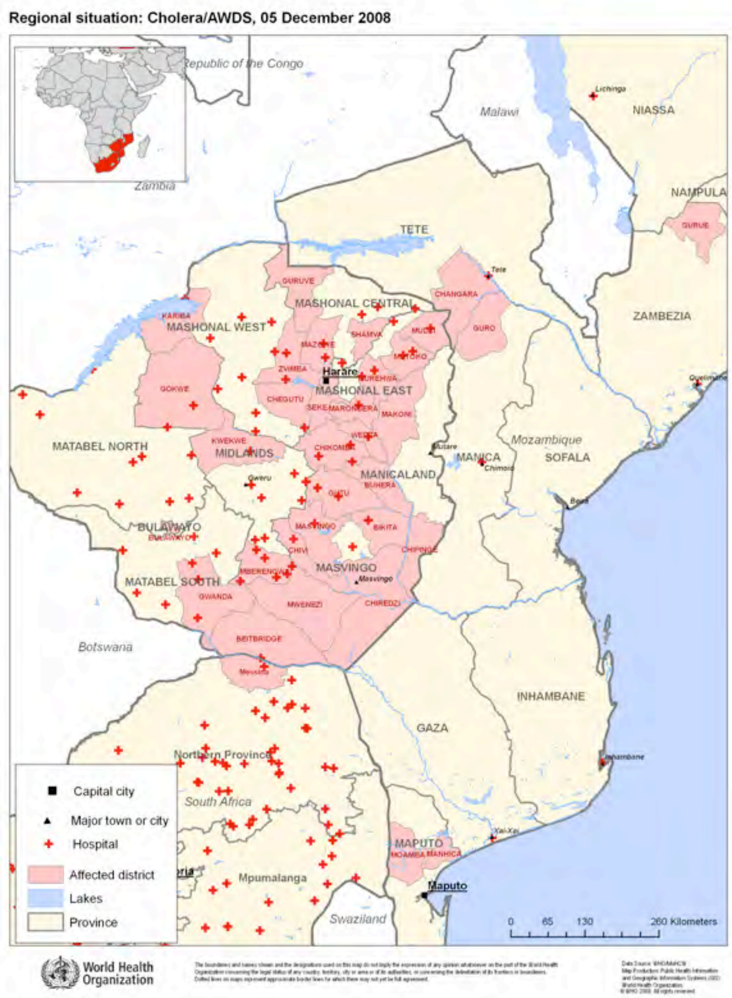

Figure 9-3: Regional spread of the 2008 Zimbabwe epidemic

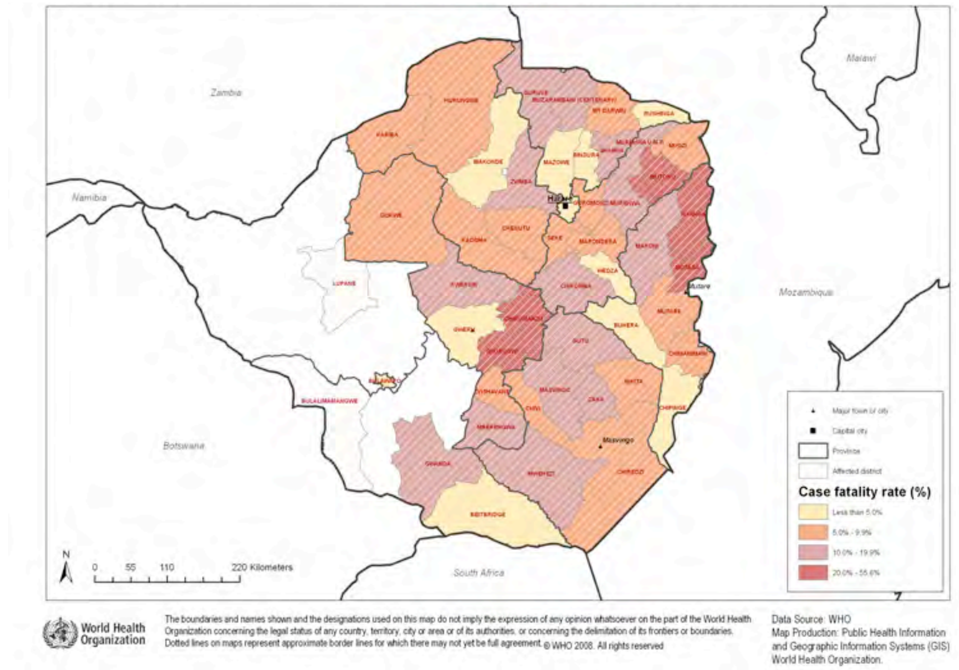

Figure 9-4.Case fatality rates for Zimbabwe by district