Chapter 4. Changes in Impacts of Climate Extremes: Human Systems and Ecosystems

Coordinating Lead Authors
John Handmer (Australia), Yasushi Honda (Japan), Zbigniew W. Kundzewicz (Poland), Carlos Nobre (Brazil)

Lead Authors
Nigel Arnell (UK), Gerardo Benito (Spain), Jerry Hatfield (USA), Ismail Fadl Mohamed (Sudan), Pascal Peduzzi (Switzerland), Shaohong Wu (China), Boris Sherstyukov (Russia), Kiyoshi Takahashi (Japan), Zheng Yan (China)

Review Editors
Sebastian Vicuna (Chile), Avelino Suarez (Cuba)

Contributing Authors
Amjad Abdulla (Maldives), Laurens Bouwer (Netherlands), John Campbell (New Zealand), Fred Hattermann (Germany), Robert Heilmayr (USA), Adriana Keating (Australia), Monique Ladds (Australia), Katharine Mach (USA), Michael Mastrandrea (USA), Reinhard Mechler (Austria), Apurva Sanghi (World Bank), Joel Smith (USA), Adonis Velegrakis (Greece), Walter Vergara (World Bank), Anya M. Waite (Australia), Jason Westrich (USA), Joshua Whittaker (Australia), Yin Yunhe (China), Hiroya Yamano (Japan)

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References

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)^{TM}, 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)

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[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 2.5°C 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*

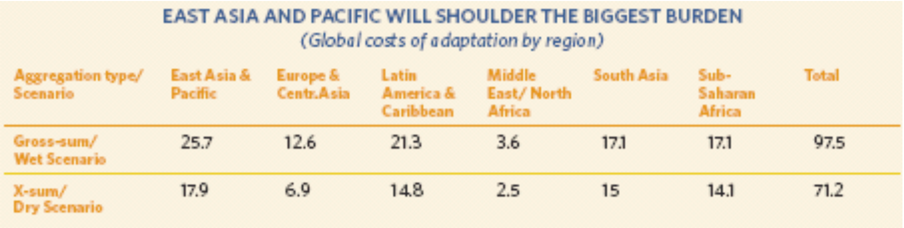
Table 4-17: Estimated Change in Disaster Losses in 2040 Under Projected Climate Change and Exposure Change, Relative to the Year 2000 from Twenty-One Impact Studies, Including Median Estimates per type of Weather Hazard (Sources: Bouwer, 2010)

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

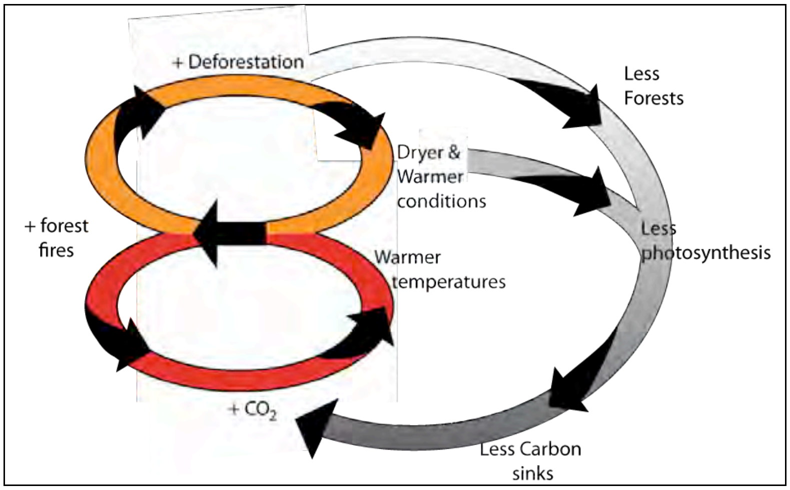


Figure 4-1: Simplified Diagram of the Positive Feedbacks between Drought, Forest Fires and Climate Change

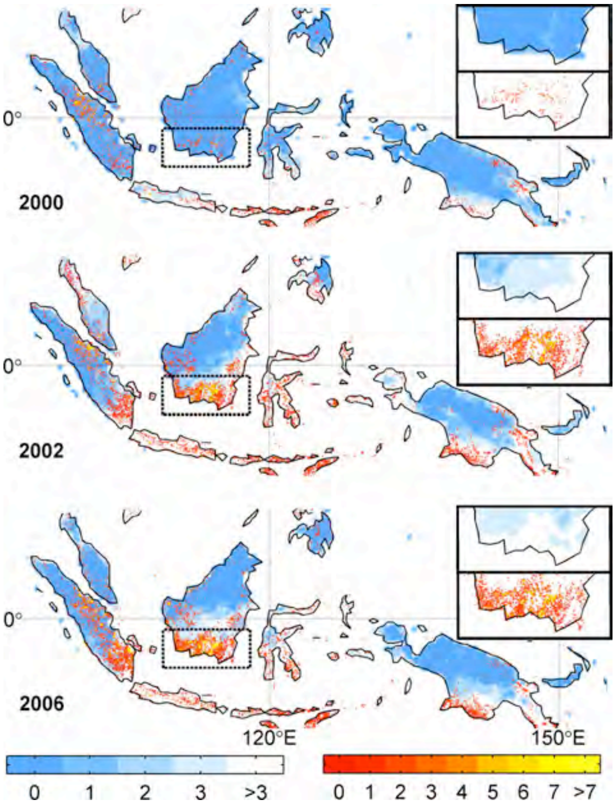


Figure 4-2: Dry Season Length and Fire Detections for the Strong 2000 La Niña and 2002 and 2006 Moderate El Niño Years

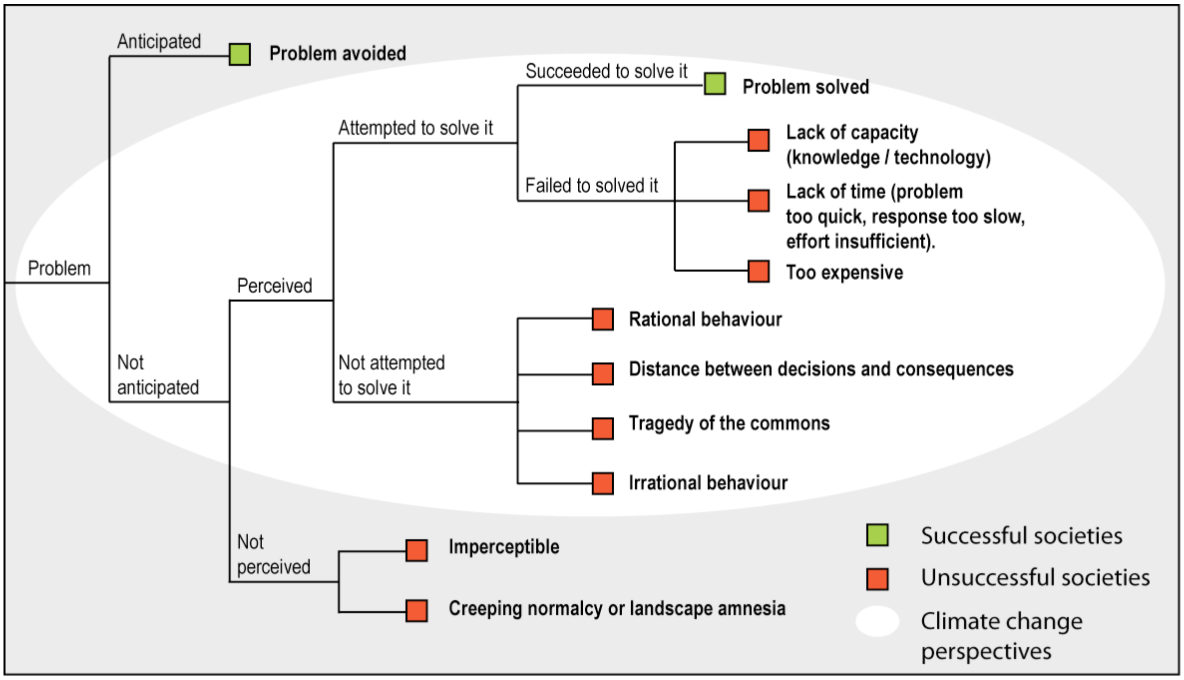


Figure 4-3: Path for Successful Problem Solving In Past Societies
Climate change share many aspects with unsolved issues (white area).

Figure 4-4: The Total Economic Losses and Insured Losses from "Great Weather Related Disasters" Worldwide (1950-2010, adjusted to present values)

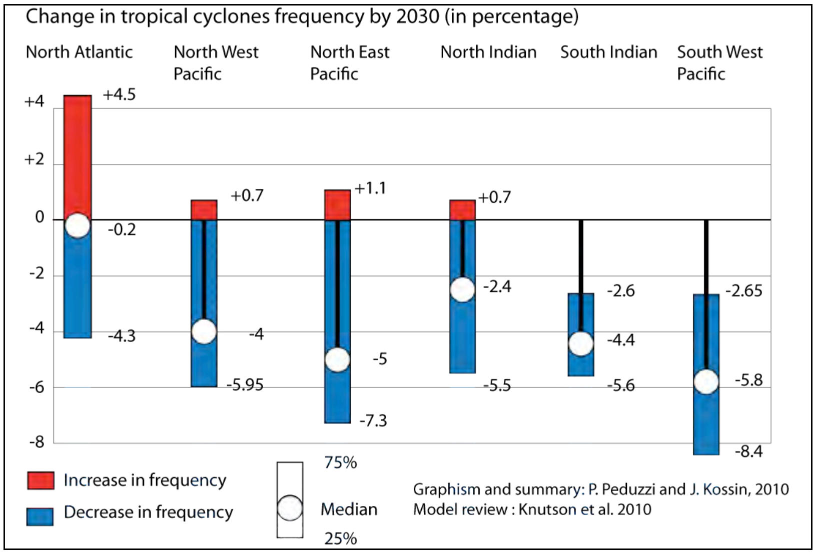


Figure 4-5: Forecast Changes in Tropical Cyclones Hazards Frequencies by 2030 (Source: Peduzzi et al. 2011; Review of Models Based on Knustson et al. 2010)

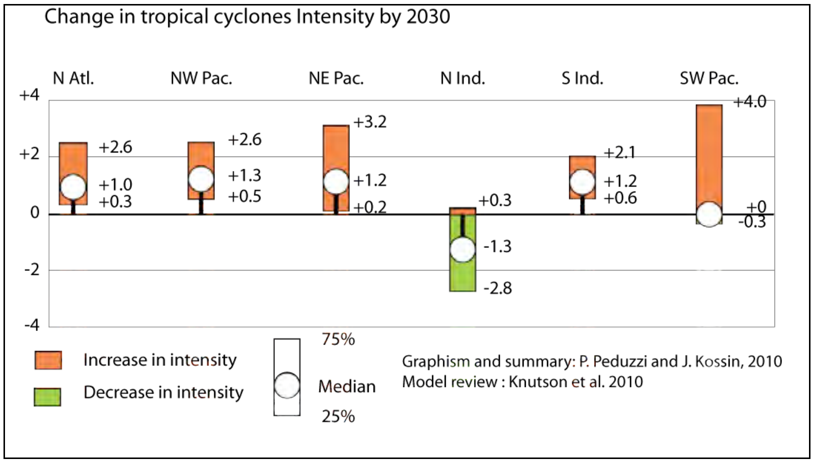


Figure 4-6: Forecast Changes In Tropical Cyclones Hazard Intensities by 2030 (Source: Peduzzi et al. 2011; Review of Models Based on Knustson et al. 2010)

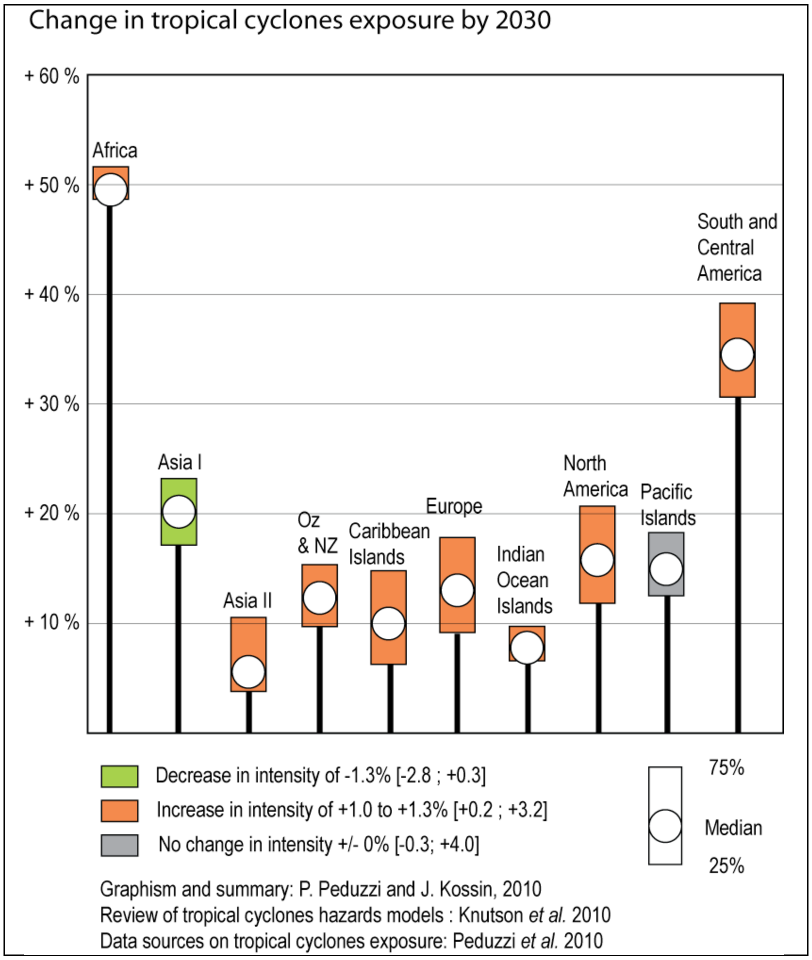


Figure 4-7: Forecast Changes in Tropical Cyclones Population Exposure (Source: Peduzzi et al. 2011)

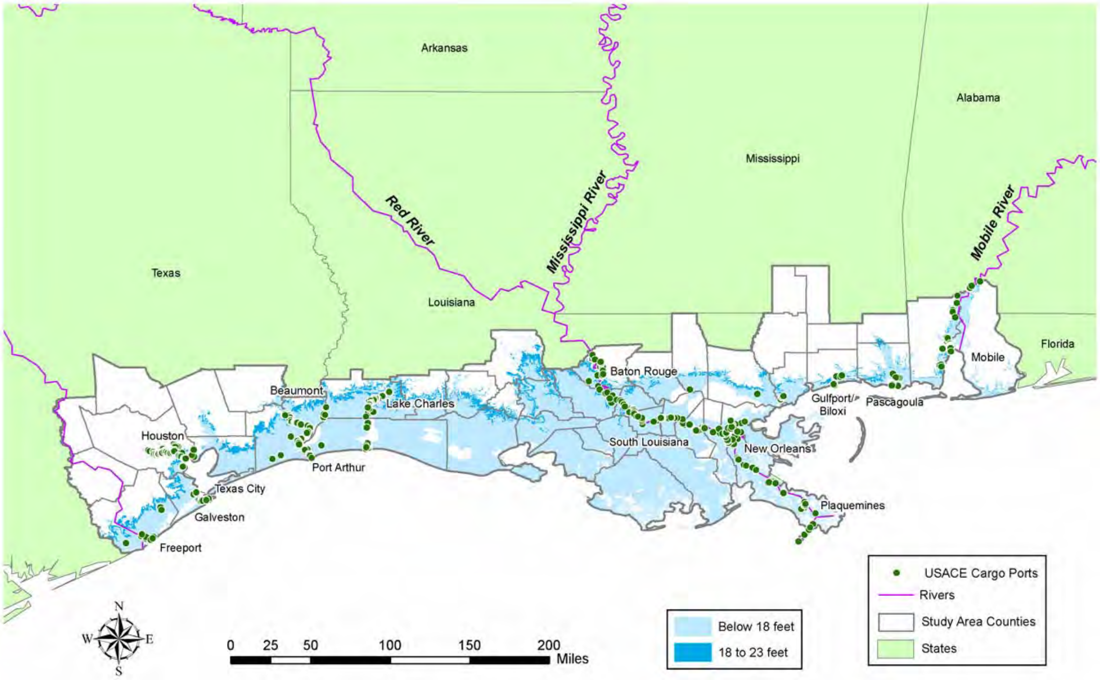


Figure 4-8: Freight Handling Port Facilities at Risk from Storm Surge of 5.5 and 7.0m in The US Gulf Coast (Source: CCSP, 2008)

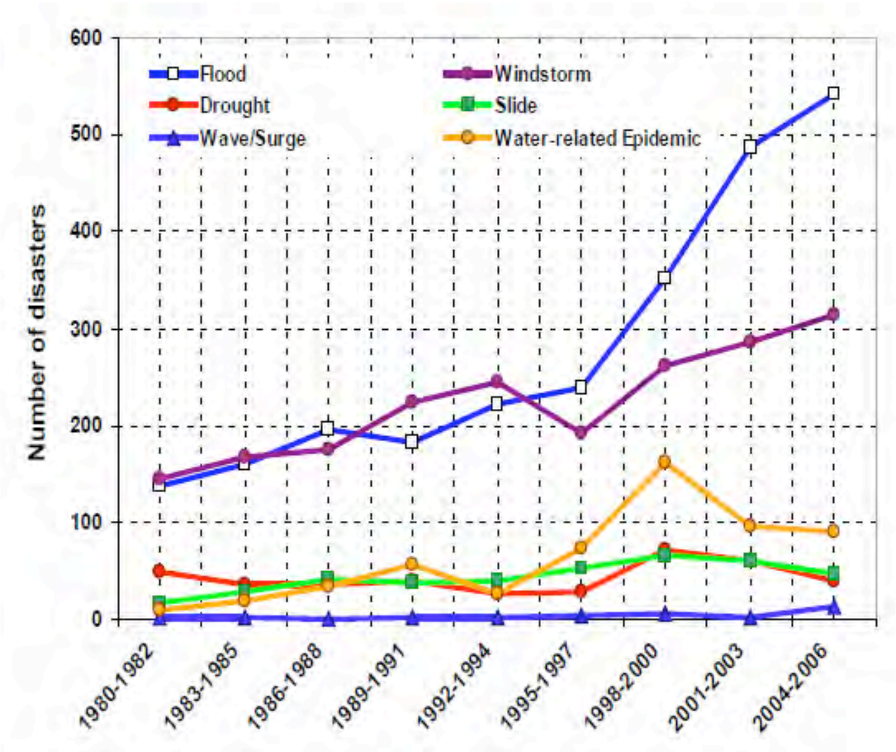


Figure 4-9: Water-Related Disaster Events Recorded Globally, 1980 to 2006 (Source: Adikari and Yoshitani, 2009)

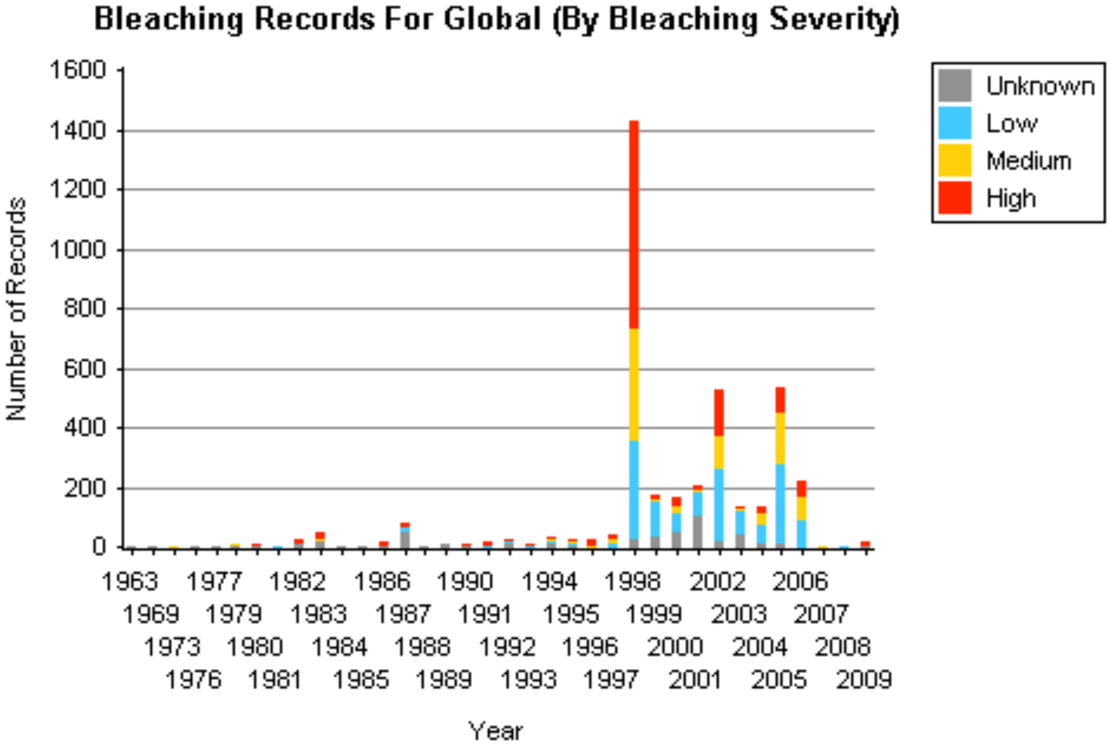


Figure 4-10: Coral Bleaching Record

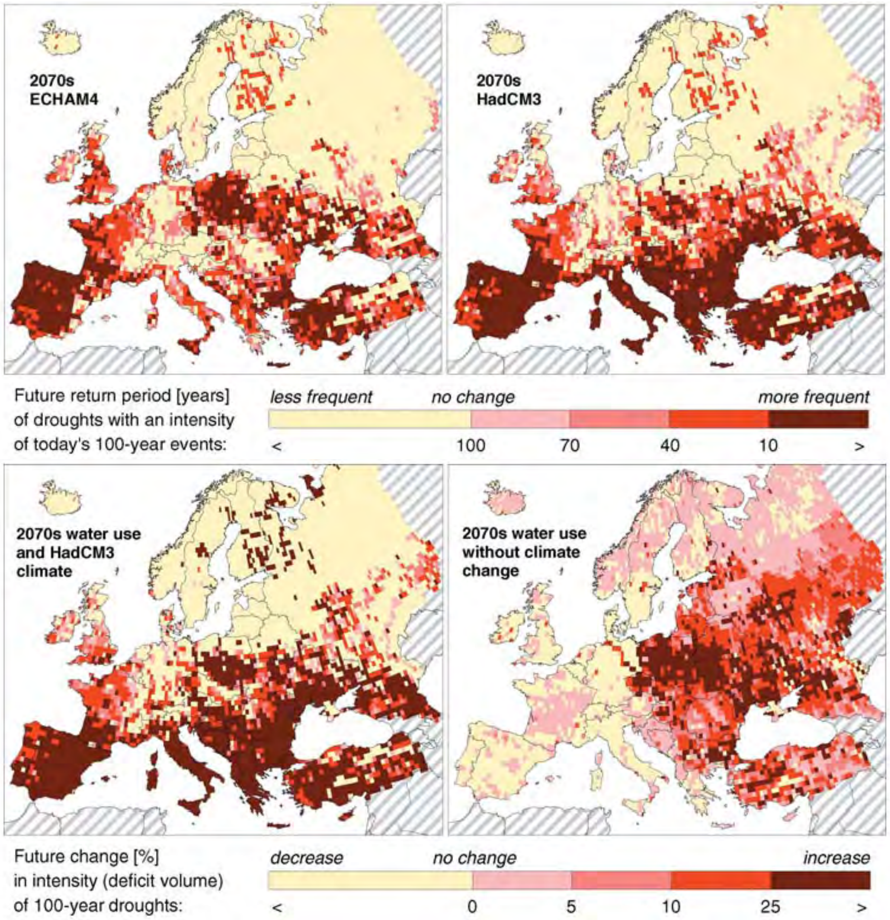


Figure 4-11: Change in Indicators of Water Resources Drought across Europe by the 2070s (Source: Lehner et al., 2006).
A (top): change in the return period of the current 100-year drought deficit volume, with change in river flows and withdrawals under two climate scenarios
B (bottom): change in the intensity (deficit volume) of the 100-year drought with changing withdrawals, with climate change (left, with the HadCM3 scenario) and without climate change (right)

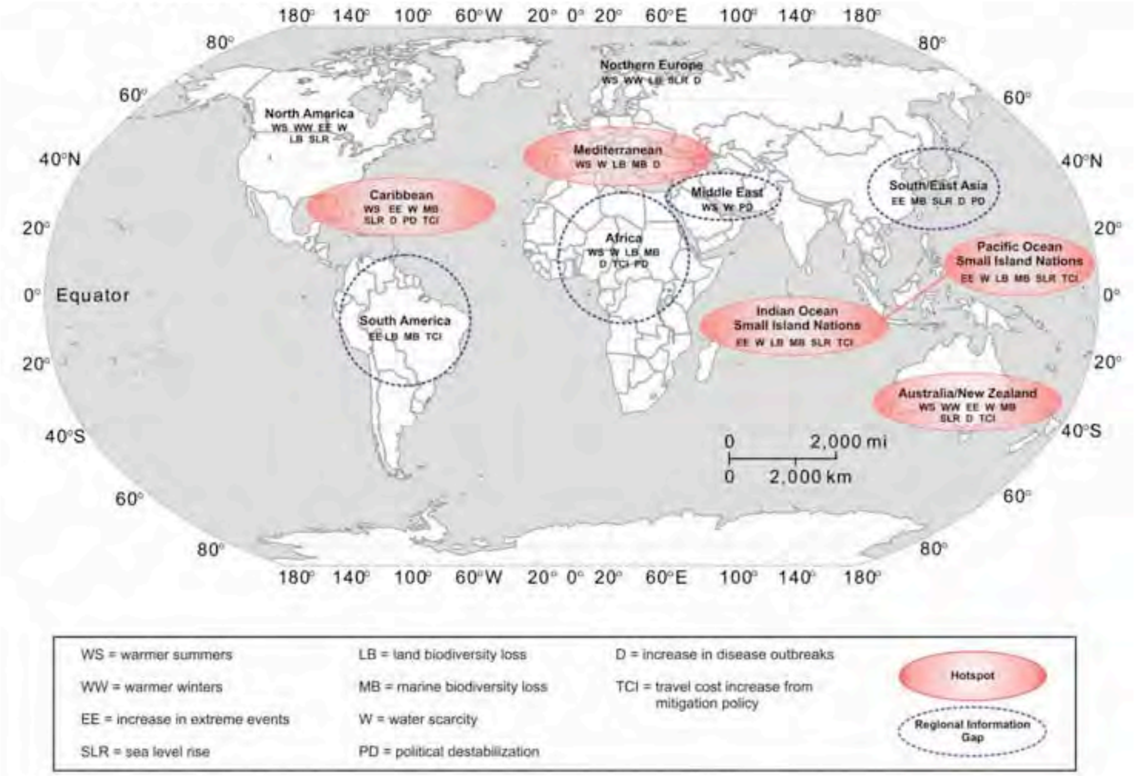


Figure 4-12: Climate Change Vulnerability Hotspots in the Tourism Sector (Source: Scott et al., 2008)

Figure 4-13: People Affected by Natural Disasters from 1971-2001 [Updated Figure on climatic disasters needed]

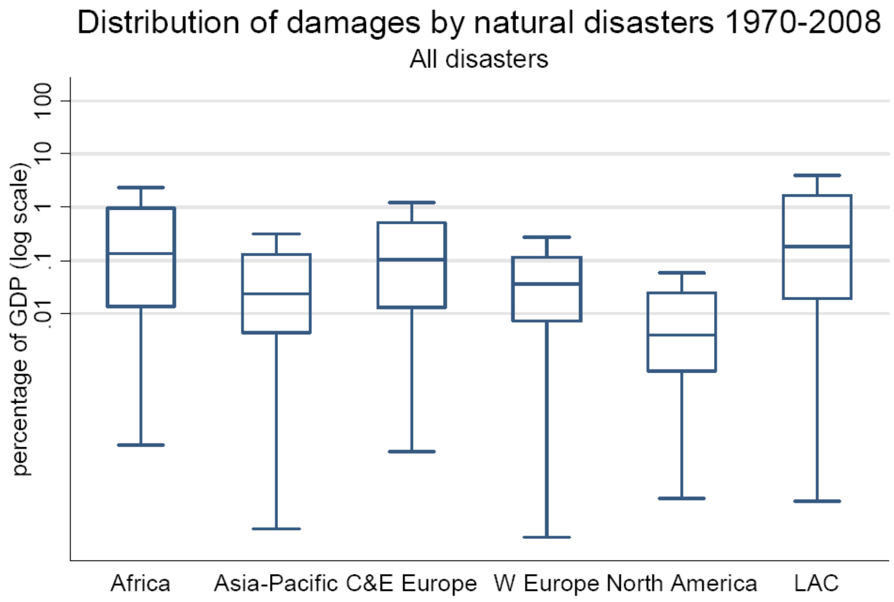


Figure 4-14: Distribution of Regional Damages as a % of GDP (1970-2008) (Source: EM-DAT, WDI database, calculated by Cavallo and Noy, 2009)

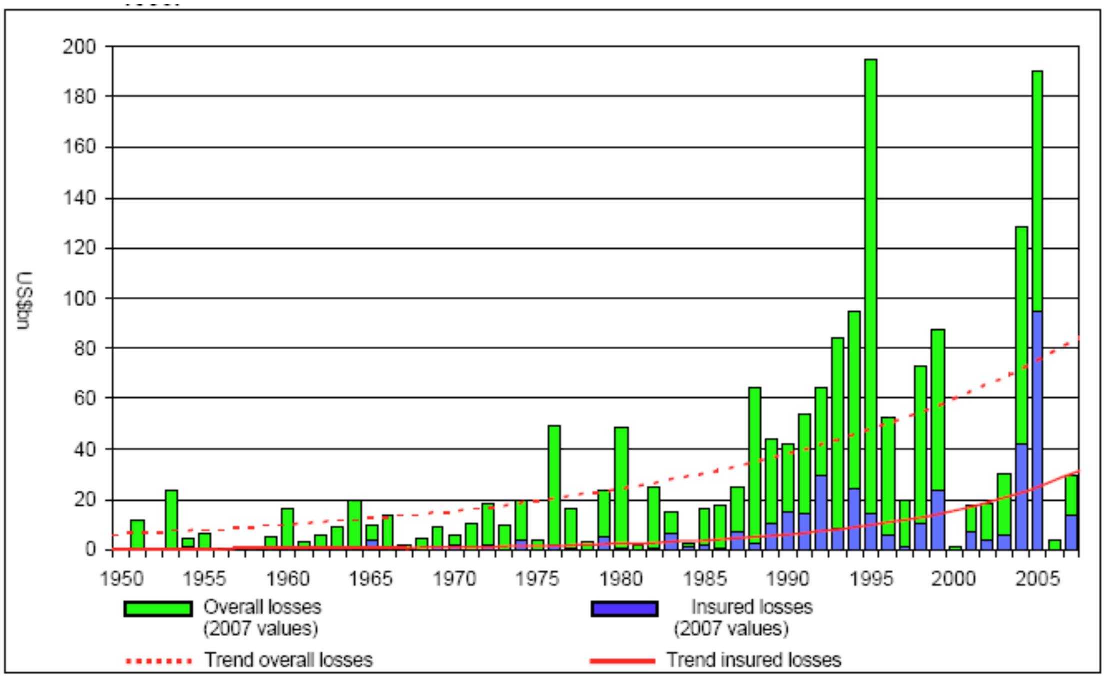


Figure 4-15: The Overall Losses and Insured Losses from Natural Disasters Worldwide (adjusted to present values) (Source: Munich-Re, 2007)

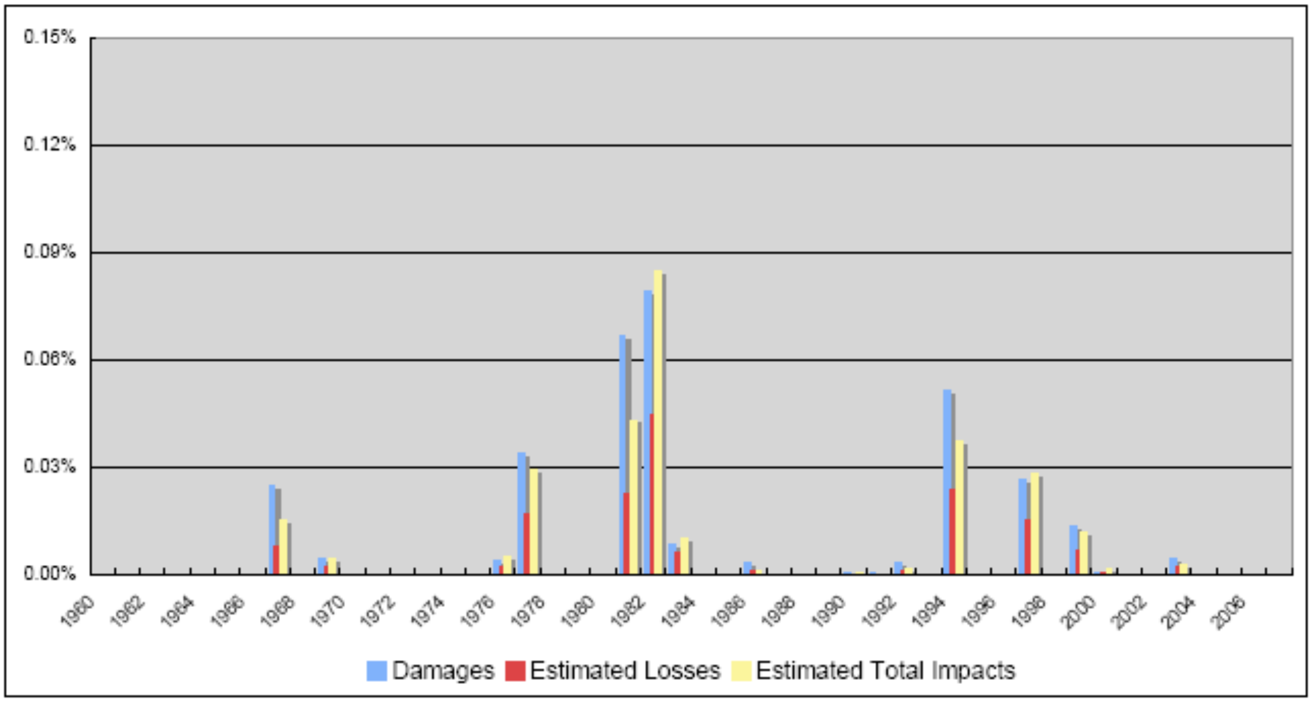


Figure 4-16: Historical Trends of Climatological Disasters (normalized)