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

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Executive Summary

This chapter is concerned with how climate and weather events impact on human and ecological systems. This is examined in terms of two distinct types of "extremes": weather and climate extreme events, and extreme impacts on human and ecological systems. Although extreme impacts often follow an extreme event, either extreme can occur without the other. The impacts of weather and climate extremes on humans and ecosystems are a function of exposure, vulnerability and the type and magnitude of the climate extreme. Or put another way the impacts of climate events are mediated by exposure and vulnerability. Extreme impacts may become disasters, especially when the impact is such that local capacity to cope is exceeded.

The chapter looks at observed and projected trends in exposure and vulnerability to, and impacts from, weather and climate events. It does this by sector and by regions. The global costs of these events are estimated and where data exist costs are also estimated for regions.

For practical reasons, both the concept of "extremes" and "rarity" are not amenable to precise definition. Varying spatial and temporal scales, and the almost infinite variation in the attributes of the event in question – such as: duration, intensity, spatial area affected, timing, frequency, onset date, whether the event is continuous or broken such as a continuous drought, and antecedent conditions - mean that it is neither practical nor useful to define extremes precisely. Statistical rarity is determined with respect to time and place, and subject to major changes.

Vulnerability" is defined here to mean susceptibility to harm and ability to recover. Exposures are human and ecosystem tangible and intangible assets and activities in the way of weather or climate events. Assessment of vulnerability and exposure should take account of temporal and spatial scales. Activities far from the site of impact can be seriously impacted. Exposure can be more or less permanent or transitory: for example, exposure can be increased by people visiting an area or decreased by evacuation of people and livestock after a warning. Exposure is a necessary but not sufficient condition for impacts. As human activity and settlements expand in a given area, more will be exposed to and affected by local climatic events.

Observed trends

On the global scale, annual material damage – which represents only part of the human impact - from large weather events, has increased 8-fold between 1960s and 1990s, while the insured damage has risen more (17-fold in the same interval) in inflation-adjusted monetary units. Attempts have been made to normalize loss records for changes in exposure and vulnerability. This allows detection of observed changes in weather hazard rather than the disaster impact. There is no conclusive evidence that anthropogenic climate change has lead to increasing losses, and increasing exposure of people and economic assets is most likely the major cause of the long-term changes in economic disaster losses. This conclusion is subject to debate and depends on the processes used to normalize loss data over time. Different studies use different approaches to normalization, and to handling variations in the quality and completeness of longitudinal loss data. These are areas of potential weakness in the conclusions of longitudinal loss studies, and need more empirical and conceptual effort. A second area of uncertainty concerns the impacts of modest weather and climate events on the livelihoods and people of informal settlements and economic sectors, especially in developing countries. These impacts have not been systematically documented with the result that they are largely excluded from longitudinal impact analysis.

The dramatic expansion of water demand (and water withdrawals) for food production, hygiene, human well-being and industry, including by the power sector, highlights some of the complexities inherent in the weather/exposure interface. These changes have exacerbated both the severity of droughts as well as societal vulnerability to droughts and water deficits.

Projected changes

Human exposure to climatic hazards is increasing. This is to some extent inevitable as population increases, as humanity expands activities in all regions and as resources are increasingly won from more difficult and expensive sources. However, the severity of the resulting impacts of climatic extremes depends on the vulnerability of what is exposed: on its susceptibility to harm and capacity for recovery. Much data on impacts conflate the effects of exposure with vulnerability as defined in this chapter.

Overall vulnerability appears to be fairly stable, although this general statement conceals a diverse range of trends including areas and groups where the trends are negative.

Higher levels of vulnerability may evolve from the sequence of natural and technological events and the interactions between them. For example, the initial disaster agent may be an invisible contaminant which affects the mental and physical health of those involved, with impacts persisting for years. Such impacts may undermine local resilience for subsequence events.

The impacts of disaster are greatest on poorest households - although this statement conceals important caveats. Poorer households may be resilient, but are rarely covered by insurance or social protection. Disaster impacts lead to income and consumption shortfalls including in education and health, and negatively affect welfare and human development, often over the long term. Poor people typically have higher levels of everyday risk, even without considering the impact of natural hazards. Many of these people are in rural areas, but many are counted among the approximately one billion people worldwide who live in informal settlements – a number growing by approximately 25 million per year.

If people do not have enough to eat in normal times, they may be particularly badly impacted by extreme climatic events. This is especially the case for those entirely dependent on their own produce for their food supply, and those whose cash livelihood depends on their own food crops. Crop-failure is a key driver for rural urban migration, which is expected to be exacerbated by climate change. Increased urbanization may also increase vulnerability to extremes.

The most devastating impacts of climate change related extremes are likely to be associated with extreme sea levels due to tropical and extra-tropical storms, which will be superimposed upon the long-term sea level rise. The impacts will be more severe for deltas, coastal wetlands and small island states, as well as poorer large urban centers. The likely impacts will be mediated by the intrinsic natural characteristics of the local system, and by human activities. One of the more significant economic effects of climate change driven extreme events in coastal areas will be associated with disruption to transportation and especially ports, which may have far-reaching implications for international trade, as more than 80% of global trade in goods (by volume) is carried by sea. Major economic impacts are also expected as a result of disruption to coastal tourism.

Impacts on ecosystems

The impacts of changes in extreme weather and climate events on ecosystems has not been well studied, and extreme events have consequences which are difficult to predict, given that such situations may be unprecedented. Nevertheless, in the Northern Hemisphere the gradual northward and upward movement of the range of many species since 1904 is likely due to the effects of a few extreme weather events on population extinction rates. The variations of the extreme events covers a large array, such as: sudden and transient temperature changes, rapid retreat of sea and lake ice, bouts of abnormally high precipitation or extended droughts, wildfires, the sudden release of water from melting glaciers, insect outbreaks, increases in eutrophication, invasion by alien species, or rapid and sudden increases in disease and slumping of permafrost. These are all examples of events that may have disproportionately large effects on ecological dynamics. Other factors induced by climate change include "false springs," and the incidence of midsummer frost, which has been directly observed to cause extinction of species.

The Millennium Assessment found that the supply of approximately 60% of the ecosystem services evaluated (15 of 24) was in decline. However, consumption of almost all ecosystem services is increasing. Demand and service flow is increasing as the stock is decreasing. As people have modified ecosystems to increase the supply of provisioning services, these same modifications have led to the decline of regulating ecosystem services, including those responsible for mitigating the hazards of fires and floods.

Regions

In most regions, extremes such as heat waves and wild fires, droughts and floods (fluvial and coastal), are projected to become even more extreme, in terms of frequency and/or intensity. Among the most vulnerable regions to climate extremes are: the Arctic, because of high rates of projected warming on natural systems; Africa, especially the sub-Saharan region, because of low adaptive capacity and increasing hazard; and small islands.

It is estimated that one-third of the people in Africa live in drought-prone areas and are vulnerable to the direct impacts of droughts (famine, death of cattle, soil salinisation). Consecutive dry years with widespread disruption reduce the ability of the affected society to cope with droughts by providing less recovery and preparation time between events. As a result of a multi-year drought, a severe famine developed in the Sahel in 1980s, causing famine and high economic damage. Forest fire danger (length of season, frequency and severity) is very likely to increase in most regions.

Small island states of the Pacific, Indian and Atlantic oceans, are regularly identified as being among the most vulnerable to climate change and climate-related disasters. In the light of current experience and model-based projections, these states, with high exposure of population and infrastructure to risk of sea-level rise and increased storm surge, high vulnerability and low adaptive capacity, have legitimate concerns about their future. Changes to climate means or variability may lead to extreme impacts. Smallness, in both area and economy, renders island countries at risk of very high proportionate losses when impacted by disaster.

Intense precipitation is on the rise in many regions, hence potential for flooding increases. The most flood-prone country on the globe is Bangladesh, where each of the three most extensive floods in the last 25 years inundated more than 60% of the country area. Projections indicate increasing flood risk in Bangladesh.

Summer heat waves have already become increasingly frequent and severe in several continents, with significant economic and human impacts.

In every region there are areas and groups of population that are vulnerable to climate extremes. During the 2003 heat wave, several tens of thousands of additional heat-related deaths were recorded in the increasingly wealthy and ageing societies of southern Europe.

Non-extreme climate events may lead to extreme impacts where system tipping points are reached – such as thermohaline circulation weakening, or collapse of the Amazon forest (‘savannization’). Similarly, oscillations in the Ocean-Atmosphere system are strong regional drivers of climate variability, affecting climate extremes.

Costs of climate extremes and disasters

Economic analysis provides information about the cost and consequences to individual and social welfare of both climatic disasters and the associated adaptation options. Macroeconomic modelling such as input-output models can be used to estimate the impact of disasters on regional or national economies. Disaster loss assessment studies look at specific disasters to estimate the economic, social and environmental impacts of disasters. Expanding the inclusion of environmental values such as ecosystem services in disaster loss assessment is an important area for future work.

The economics of adaptation to extremes is an emerging field. Adaptation studies for developed and developing countries have focused on the costs of adaptation to slower onset climatic changes rather than impacts and damage costs of extremes. Most adaptation studies can be split into four major categories (i) Assessing vulnerability (building on assessments contained in NAPA); (ii) Building institutional capacity (climate information, skilled professionals, and so on); (iii) Piloting adaptation strategies; and (iv) Operational adaptation (needed to cope with new hazards and conditions). The existing estimates of adaptation cost have some weakness in methodology: a) omission of some economic sectors, such as ecosystems, tourism, etc, and b) a lack of consideration for “adaptation deficit” which is relevant to climate proof investment

The experience of disasters and the capacity to adapt varies greatly between developed and developing countries, but also within them. In general, the relationship between development and disaster impacts means a wealthy or richer country relates to a safer country, since a higher income level, governance ability, higher education rate, climate proof investment and insurance system reduce the human cost and economic impact of extreme events and disasters. While the countries with highest income account for more in dollar terms of the economic and insured losses from disasters, a greater portion of GDP and higher fatality rates are generally seen in developing countries, which imposes a greater burden on governments and individuals in those countries. Although there is an absence of any conclusive agreement regarding the long term effects of disasters, it is very likely that poorer developing countries and smaller economies are likely to suffer more from future disasters than developed countries.

Disaster risk management, climate change adaptation and sustainable development are intrinsically linked, and these fields could benefit from increased integration in both theory and practice. Particularly in developing countries with limited adaptation options, initiatives that increase community resilience, such as increasing financial resilience via income diversification and insurance, will have benefits for disaster risk management, climate change adaptation and sustainable development.

4.1. Introduction

Chapter 3 establishes the current status and possible changes in the frequency and intensity of weather and climatic extremes. In doing this they have kept closely to purely natural climatic and weather phenomena. Extremes seen as having a human dimension such as wildfires and erosion are covered in this chapter.

This physical basis provides a picture of climate change and extreme natural events. But it does not by itself indicate the impacts experienced by humans or ecosystems. For some sectors and groups of people severe impacts may result from relatively minor weather and climate events. To understand these impacts triggered by natural events we need to examine the exposure and vulnerability of humans and ecological systems. We also need to clarify what constitutes impacts for whom at what scales.

This chapter examines impacts on human and ecological systems in two ways: the impacts of weather and climate extremes; and secondly, circumstances where severe or extreme impacts are triggered by less than extreme weather events. These two ways of viewing impacts are also examined by regions and sectors – as available data permit,

Activities undertaken as disaster risk reduction may also act as adaptation to climate extremes resulting from climate change, and act to reduce impacts. Strategies to reduce risk from one form of climate extreme may also increase the risk from another. In writing this chapter we have not considered these issues as subsequent chapters are dedicated to adaptation.

4.2. Role of Climatic Extremes in Natural and Socio-Economic Systems

4.2.1. What is "Extreme"?

In the context of this chapter, "extreme" refers to two distinct areas: weather and climate extreme events; and to extreme impacts on human and ecological systems. Although extreme impacts often follow an extreme event, either extreme can occur without the other. The human and ecological impacts of weather and climate events, whether extreme or not, are mediated by exposure and vulnerability. To reiterate the statement on this issue in Chapter 1, Section 1.1.3.2:

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

The definition is expanded further in Chapter 3, Box 3-1:

> "[Weather and climate events that are not statistically rare] …may also be associated with extreme impacts, in particular if they are linked with the crossing of important thresholds: e.g., a medium deficit in precipitation in a region where mean evapotranspiration has significantly increased, moderately extreme ENSO events, or specific temperature thresholds for human health. Also the accumulation of several events which may each only be mildly extreme can lead to extreme impacts, as is the case for compound events or multiple clustered events (Section 3.1.4 and Box 3.4). Reversely, an extremely rare event may not necessarily lead to major impacts and disasters if it is not associated with some critical thresholds for the impacted systems (either by its nature or because of adaptation). Most global studies of changes in physical extremes do not consider how such extremes are related to actual impacts in the affected regions".

"Extreme events" are atmospheric phenomena, quite separate from human agency.

To quote from IPCC-AR4 (see also Chapter 3, Section 3.1.1.1):

> "[An] Extreme weather event [is an] event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense.
>
> Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season)."

For practical reasons, both the concept of "extremes" and "rarity" are not amenable to precise definition. The varying spatial and temporal scales, dependency on the climate state and context "means that it is not practical nor useful to define extremes precisely" (Chapter 3, Sections 3.1.1.1 and Box 3.1), for example attributes of the event in question vary almost endlessly: duration, intensity, spatial area affected, timing, frequency, onset date, whether the event is continuous or broken such as a continuous drought, and antecedent conditions. Statistical rarity is determined with respect to time and place, and subject to major changes. A rare event in the present climate (100-year flood or 99%-percentile temperature or sea level) may become common under future climate conditions, and cease to be "rare". The impacts of such changes depend on the affected society's capacity to absorb or adapt to new circumstances. From an impacts perspective, one issue is that a percentile approach typically conflates relatively frequent events with the worse case scenarios.

There are however additional dimensions including event sequencing or seriality, compounding and interactions with other trends. This includes events occurring on top of gradual shifts in climate. Extreme events, and sometimes extreme impacts, may occur as a result of normal climate variability such as El Niño and tropical cyclones. Also, extreme events (such as floods, droughts, landslides, wildfires) and consequential extreme impacts may occur as the result of the (extreme) combination of several non-extreme events (also see Section 3.1.4). Such events may be significantly exacerbated by the underlying trends, potentially resulting in non-linear effects, eg a shift to a drier climate with long periods of unusually high temperatures exacerbating drought and water shortages and creating enhanced conditions for major wildfires. There is also the issue of the difference between an absolute extreme such as a day over 40C and a relative extreme such as the 95% percentile). Chapters 1 and 3 examine these dimensions.

Mathematically speaking, extremely high mean annual temperature also belongs to the realm of climate extremes. Among 14 warmest calendar years in the global instrumental observation record, available since 1850, there are 13 years from 1995–2008 (cf., IPCC, 2007, updated). Each of the years 2001–2008 belongs to a set of ten globally warmest years in the history of instrumental record. In the category of average temperature of consecutive 12 months, a recent record was set from July 2006 to June 2007 in several spatial scales (including Europe, and the Northern Hemisphere), cf. Kundzewicz *et al.* (2008).

Not all occurrences of extreme values of hydro-climatic variables cause damage. Some of them may bring benefits, e.g. floods can bring human benefits as with the Nile floods in history and ecological benefits as with the flooding of Lake Eyre in Australia making the adjacent desert bloom (ref. to Kotwicki).

4.2.1.1. Role in Human Systems

Extreme events and impacts have very high profile, are fodder for global media and politics, and people almost everywhere seem motivated to support those suffering severe impacts as a result of weather and climate events. However, greater effort likely goes into preventing the impacts of the more frequent events through adaptation of routine or day-to-day design and management of activities and structures across most aspects of human systems. This includes major roles in religion and spirituality, and in people's minds. While most attention goes on the negative impacts, extremes may also generate economic benefits (eg Handmer and Hillman 2003), and in many cases some social benefits due to community solidarity. As well, the effort that goes into building and otherwise preparing for extreme events may generate much economic activity.

_____START BOX 4-1 HERE _____

Box 4-1. The Collapse of Past Societies.

While we are talking about extreme impacts and the capacity for adaptation, it might be useful to look at why some past societies did not adapt to either climate or environmental changes. In his book Jared Diamond (2005) describes many examples of the collapse or failure of past societies. This can be viewed as an extreme impact and there are no certainties on whether our civilisation will succeed in solving the challenge posed by climate change.

To succeed, a society needs either to anticipate a problem, hence having an excellent understanding of all processes and interactions. Alternatively if a problem was not anticipated, it needs to be perceived (monitoring) and then adapted to through a society's resilience. This requires the political will to attempt to solve the problem. Finally the society must have the know-how, the technology and the resources to solve the problem.

Climate change is a complex issue and shares many of the threats of unsolved problems, such as rational behaviour, tragedy of the commons, irrational behaviour, creeping normalcy and distance between decisions and consequences.

[INSERT FIGURE 4-1 HERE:
Figure 4-1: A path model to societal success or failure.]

_____ END BOX 4-1 HERE _____

In some cases extreme events and extreme impacts have led to major changes in regulations, organisations and policy (eg. Melbourne 2009 Fires, the Indian Ocean 2004 tsunami). In a few cases extreme events may have resulted in dramatic change or abandonment of affected areas (such as the US dust bowl, Egan 2008; parts of inland Australia, Radcliffe 1938), or even the collapse of societies (eg. Diamond 2005). These examples of abandonment and collapse illustrate the need to consider worse case scenarios as well as more frequent and familiar events and impacts.

Historically there are some well known examples of humans undertaking deliberate large scale modification of the natural environment as a direct result of climate extremes. These include the drainage of the Fens in England between the middle ages and 1800s (Ravensdale 1974), the protection of the Dutch coast, and hydraulic engineering feats in the Middle East and Asia (Wittfogel 1957). More generally humans responded to extremes by attempting to manage exposure, for example by avoiding the occupation of areas prone to flooding, and by reducing vulnerability through for example raising dwellings in flood prone areas, or by ensuring food availability in spite of droughts or frosts. The emphasis today appears to be on managing vulnerability as avoiding exposure seems increasingly difficult as humanity spreads into every location.

Today, considerable effort around the world is devoted to preventing, reducing and managing the impacts of extreme events.

Poorer rural areas where livelihoods are heavily or solely dependent on farming or fishing, have housing that is easily damaged by weather events and have limited access to government and commercial services, are particularly susceptible to severe impacts from extreme events and may have limited capacity to recover (XX). Under these circumstances relatively frequent natural events may result in extreme impacts. Response is seen in the pattern of land cropped, in the mix of crops and the preference for low yielding reliable strains over high yielding modern varieties. Extremes force a search for livelihood diversification, dependence on relatives especially remittances from those working elsewhere, and aid funds. Although micro insurance is increasingly available, uptake has been limited (Levin and Reinhard 2007). The livelihoods of the urban poor are not as directly tied to climate, but the security of their housing and well being may be.

Wealthier societies and areas expend much effort to reduce the impact of extremes and to adjust to regular weather events. They do this through design standards for all infrastructure, buildings etc; for example, every road, bridge, large dam and drainage system is designed for a specified flood frequency. Every structure is designed for certain wind speeds, and so on. Wealth and trade are employed to compete globally for scarce resources, such as food, thereby insulating their own societies from the impact of food and other shortages brought on by local extreme events. However, this may simply transfer the negative impacts of an extreme from a wealthy area to a poorer one. More formal approaches to risk transfer have evolved (and continue to evolve through micro insurance and by different approaches to risk analysis for example) in particular through the expanding use of insurance and various forms of post-impact aid both of which transfer the dollar costs of impacts in space and time. Some aspects of the approach in wealthier countries are very energy intensive and produce significant carbon.

In wealthier countries, these building standards and insurance and emergency management systems are calculated explicitly (eg flood frequencies and insurance premiums) or implicitly (eg investments in warning and emergency management systems) against certain levels of risk – where risk is expressed through the occurrence of extreme climatic events, exposure and vulnerabilities. The result is a reasonably high level of insulation against climate extremes. But there are sectors of any country that are very susceptible to the impacts of extremes including agriculture and weather dependent tourism. There are also groups of people such as the homeless and many of the elderly whose circumstances expose them or render them vulnerable to certain climate extremes such as heatwaves and cold. Similar comments may also apply to other groups such as minority ethnic groups, indigenous people and women.

People in poorer countries are generally far less insulated from climate extremes. Many are preoccupied with day to day existence in a context where even frequent events result in severe impacts. Richer countries generally suffer much larger economic losses from disasters when measured in terms of the dollar value of damaged assets and disrupted cash flow, but when measured in terms of proportion of GDP it is poorer countries, especially small countries, that suffer by far the most (*needs updating* XX):

- Honduras, Hurricane Mitch, 1998: 75 percent of GDP
- Turkey, earthquake in 1999: 7-9 percent of GDP
- USA, Hurricane Andrew, 1992: <1 percent of GDP.

Most of the human impact of natural disasters is in the developing world, as shown by the following figures illustrating the dramatic difference between rich and poor countries (IFRC 2001 – from the IFRC database of 2557 disasters from 1991 to 2000):

- HDC (highly developed countries): 22.5 deaths per disaster
- MDC (countries with a medium level of development): 145 deaths per disaster
- LDC (least developed countries): 1,052 deaths per disaster.

Climate extremes, exposure and vulnerability are characterised by dynamism. Major changes to any of these key risk components will have significant implications in terms of both the impact of extreme events and their likely role in human systems. In the short term the main implications are for the groups that traditionally manage disasters and emergencies. They are and likely will be seen as responsible for managing these evolving risks and the increased complexity in impacts they bring.

Changes to underlying climate with extremes superimposed [needs completing].

4.2.1.1.1. Case Study – Sidr (2007) in Bangladesh versus Nargis (2008) in Myanmar

Although 15% of the world tropical cyclones occur in the North Indian Ocean (Reale *et al.*, 2009), they account for 86% of mortality risk (ISDR, 2009). This is due to high population density in exposed areas and poor governance in this region. This vulnerability is particularly of concern given that frequency of tropical cyclones in the North Indian Ocean has registered increasing trends during summer monsoon, which seems to be primarily due to decrease in the vertical wind shear (Muni Krishna, 2009). Intensity trends seems also to be increasing as half of the 8 major tropical cyclones since the last 25 years, were recorded in the three years between 2006 to 2008 (Webster, 2008). Although, data availability and changes in measuring methods makes it difficult to address tropical cyclones trends (Landsea *et al.*, 2006), prudence calls for improving forecasting and mitigation in order to reduce casualties and property damage (Webster, 2008).

Storm surge will be exacerbated in case of climate change leading to more intense tropical cyclones (see Chapter 3) as well as by sea level rise. Storm surges will also be increased by other human activities leading to soil subsidence, such as extraction of oil, gas and water from deltas (Syvitski *et al.*, 2009). Knowing that 80% of victims from Nargis were killed by storm surge and that early warnings do not systematically include storm surge warnings (Webster, 2008), gives cause for concern.

In Bangladesh serious efforts to decrease risk from tropical cyclones were made (Paul, 2009). This was highlighted by the low number of casualties from Sidr in 2007 (Paul, 2009). This contrasts vividly with the outcome of Nargis in Myanmar, where the death toll exceeded 138,000 fatalities making it the eighth deadliest cyclone ever recorded worldwide (Fritz *et al.*, 2009).

To better understand the differences between these two events of similar intensity, it might be useful to compare them as well as their respective contextual situations.

Characteristics and consequences of Sidr and Nargis
Sidr affected Bangladesh in November 2007. Its maximum wind speed reached 245 Km/h (Paul, 2009). Between 8 and 10 million people were exposed/affected (PREVIEW, 2009) and (CRED, 2009). The storm surge reached between 5-6 m (Paul, 2009). The total of reported killed was 4,234 (CRED, 2009). Nargis hit Myanmar on 2 May 2008. Its maximum wind speed reached 235 Km/h (Webster). Between 2 and 8 million people were exposed/affected (PREVIEW, 2009; CRED, 2009). The storm surge reached between 4 m (Webster, 2008). The total of reported killed was 138,366 (CRED, 2009). This summarizes the characteristics of both hazardous events and related contextual parameters.

How Bangladesh Reduced Risk from Tropical Cyclones
Lessons learnt from past exposure
Bangladesh has a significant historical record of large scale disasters. It experienced 15 disasters of more than 1000 casualties since 1960, including the infamous Gorky (April 1991, 138,866 killed) and the November 1970 tropical cyclone which lead to 300,000 deaths (CRED, 2009).

After the devastating cyclone of 1970, the Bangladesh government initiated several structural and nonstructural measures (Paul, 2009). This consists of three major actions:

a) Implementation of an early warning system,
b) Construction of public cyclone shelters and
c) Construction of shelters to provide protection for cattle during storm surges.

Nearly 43,000 volunteers disseminate cyclone warnings among villagers via megaphones and by house-to-house contact. Nearly 4,000 (3,976) shelters were built.

According to field survey (Paul, 2009), 86% of population were aware of the coming of Sidr and 3.2 millions people were evacuated (Paul, 2009).

Environmental features

The 590,000 ha of the Sunderban mangroves and coastal forests proved to be effective barriers to cyclones, during Cyclone Sidr (GOB, 2008). In Bangladesh, a coastal reforestation program was initiated in 1960, covering about 159,000 ha on coastal land, the riverine coastal belt, and abandoned embankments. These plantations reduced the impact of previous cyclones and floods as well as created employment opportunities (GOB, 2008). Their effectiveness as a barrier to cyclones depends on the width of the plantation, the number of stems per unit area, the size of the trees, the effect of branches and the roughness of the land (GOB, 2008).

Cyclone Sidr show that coastal reforestation protects embankments against cyclonic surge and monsoon waves – with the tremendous additional benefit of greatly reducing the impact of the storm surge (GOB, 2008).

Situation in Myanmar, Nargis 2008

Low past exposure to large scale event

Prior to Nargis (2 May 2008), Myanmar had experienced only one disaster with more than 1000 deaths from a tropical cyclone since 1960 (CRED, 2009). As for Nargis, this previous event also occurred in May (10 May 1968). During north hemisphere spring, North Indian Ocean experiences the highest temperature on the planet, along with a low vertical wind shear, conditions which are favorable for the development of tropical cyclones (Webster, 2008).

This was the first time that Myanmar experienced a cyclone of such a magnitude and severity (Lateef, 2009) and “the path of the storm could not have been worse” (Webster, 2008).

It should be noted that several unfavorable conditions were combined for this hazardous event to be transformed into such a large-scale disaster.

Early warning

Early warning was incomplete; the Indian meteorological department has the responsibility to issue warnings for the region, but has no mandate to provided storm-surge forecasts. Myanmar’s official forecasts appeared on page 15 in the newspaper The New Light of Myanmar from 29 April to 2 May, suggesting that the media underestimated the threat, thus resulted in insufficient warning to the population (Webster, 2008).

Conclusions

With an estimated $1,500 (2008 estimated) GDPppp for Bangladesh and $1,200 (2008 estimated) for Myanmar (CIA, 2009), these are both very poor countries. However, the difference in poverty cannot explains all. World Bank developed a series of indicators on governance (WorldBank, 2009). It is clear that there are significant differences when ranking the quality of governance between Bangladesh and Myanmar: notably in voice and accountability (31), Rule of Law (22), Regulatory quality (20), Government effectiveness (20). Low governance and especially “voice and accountability” issues were highlighted as one major vulnerability component of human mortality risk to tropical cyclones (Peduzzi, 2009).

While two different hazardous events cannot necessarily be compared, the large discrepancy in resulted casualties recorded appears highly significant.

Despite Nargis being both slightly less powerful and affecting fewer exposed people, as compared with Sidr, the resulting human loss was 32 times higher. Comparison between these two events and countries suggests that awareness (past occurrence of large scale disasters) and improved governance (manifest in improved early warning systems, evacuation plans, infrastructure and the protection of healthy ecosystems) are helping to cope with extreme events.

[INSERT TABLE 4-1 HERE:
Table 4-1: Sidr versus Nargis: general figures (compiled from CRED 2009, Paul 2009, Webster 2008).]

4.2.1.2. Role in Natural Systems [this needs expanding]

Many ecosystems are dependent on extremes for reproduction (fire, floods, wind dispersal), disease control (cold, dry periods), and in many cases general ecosystem health (fires, windstorm etc allowing new growth to replace old).

How these events interact with other trends and circumstances can be critical to the outcome. Floods that would normally be essential to river gum reproduction may carry disease and water weeds; fires that are key to the reproduction of eucalypt species may occur in very dry conditions when plants are stressed by other factors such as drought, disease and competition from weed species.

4.2.2. Complex Interactions between Climate Events, Exposure and Vulnerability

There exist complex interactions between different climatic and non-climatic hazards, exposure and vulnerability that have the potential of triggering complex, scale-dependent impacts.

Human-induced changes in climate and atmospheric systems are believed to be driving changes in climatic variables and corresponding impacts. However, the impacts that climatic extremes have on humans and human-altered environments depends also on several other non-climatic factors (Adger, 2006). This section will explore these factors with reference to extreme precipitation events and flooding. Box 4.2 illustrates some of these issues for wildfires.

Changes in socio-economic patterns are a key component of exposure; in particular population growth is a major driver behind changing exposure and vulnerability (see Barredo, 2009; Downton, Miller and Pielke, 2005). In many regions, people have been encroaching into, and developing, floodplains and other flood-prone areas (Douglas *et al*, 2008; McGranahan, 2007). In these areas both population and wealth are accumulating, thereby increasing the flood damage potential. In many developing countries, human pressure and lack of more suitable and available land often results in encroachment onto urban floodplains. Urbanization, often driven by rural poverty, drives poor people to migrate to areas where effective flood protection is not assured (Douglas *et al*, 2008). Here we see a key tension between climate change adaptation and development; living in these areas without appropriate adaptation is mal-adaptive from a climate change perspective, but this may be a risk people are willing to take, or over which they have limited choice, considering their economic circumstances (Wisner et al., 2004). Furthermore, there is often a deficient risk perception present, stemming from an unjustified faith in the level of safety provided by flood protection systems and dikes in particular.

Economic development and land-use change can also lead to changes in terrestrial systems (hydrological systems and ecosystems). Land-cover changes induce changes in rainfall-runoff patterns, which can impact on flood risk. Deforestation, urbanization, reduction of wetlands and river regulation (channel straightening, shortening, embankments) change the conditions under which precipitation becomes runoff by reducing the available water storage capacity (Few, 2003; Douglas *et al*, 2008). These transformations can also contribute to loss of natural inundation areas (e.g. elimination of floodplains, wetlands, and wash-lands) and infiltration capacity. Furthermore they increase the proportion of impervious area (roofs, yards, roads, pavements, parking lots, etc.) and the value of the runoff coefficient. As a result, water runs off faster to rivers or the sea, and the flow hydrograph has a higher peak and a shorter time-to-peak (Few, 2003; Cheng and Wang, 2002; Douglas *et al*, 2008), reducing the time available for warnings and emergency action. In mountainous areas, developments extending into hilly slopes are endangered by landslides and debris flows, triggered by intense rains. These changes have resulted in less extreme rain leading to serious disaster.

Similarly, droughts should not be viewed as exclusively physical or natural phenomena. Their socio-economic impacts may arise from the interaction between natural conditions and human water use, which can be conceptualized as a combination of supply and demand factors. Human activities (such as over-cultivation, overgrazing, deforestation) have exacerbated desertification of vulnerable areas in Africa and Asia. Desertification is seen where soil and bio-productive resources became permanently degraded. An extreme example of a man-made, pronounced, hydrological drought comes from the Aral Sea basin. Due to excessive and non-sustainable water withdrawals from the tributaries (Syr Darya and Amu Darya), their inflow into the Aral Sea has shrunk dramatically (Micklin, 2007).

The climate change impact on sectors depends not only on changes in the characteristics of climate-related and sector-relevant variables, but also on such system properties as: pressure (stress) on the system, system management (also organizational and institutional aspects), and adaptive capacity. Climate change is likely to challenge existing management practices by contributing additional uncertainty (McGranahan, 2007).

Possible interactions of several hazards may also be an increasing threat, where cascading and conjoint effects result in increasing threats to society. Hazards may trigger others (as heat wave and drought may trigger wildfire) or exacerbate their effects. Temperature rise leads to permafrost thaw, reduced slope stability and damage to buildings. The triggering effect is also likely to be size-dependent. Several climatic hazards, independent of each other, have the potential to affect the same area, even in one season. Examples of conjoint hazards are: heat wave, drought and wildfire. A severe drought following a high intensity wildfire, which itself would most likely occur during a period of heat and water stress, will likely have major negative impacts on post-fire ecological recovery. In case of cascading hazards, one hazard influences other hazards, e.g. intense precipitation leads to flash flood, land slides and infrastructure damage – collapse of bridges, roads, and buildings, and interruption of power and water supplies. It is worthwhile to note that cascading system failures (e.g. among infrastructure) can happen rapidly and over large areas due to their interdependent nature.

_____ START BOX 4-2 HERE _____

Box 4-2. Evolution of Climate, Exposure, and Vulnerability – The Melbourne Fires, 7 February 2009.

The Melbourne fires demonstrate the inter-relationships between the climate and weather related phenomena of drought, extreme heat and wildfire. Together these created the conditions for major uncontrollable wildfires. A rapidly expanding urban-bush interface and valuable infrastructure provided the values at risk and the potential for disaster. There was a mixture of natural and human sources of ignition, showing that human agency can be key to such fires.

Saturday 7 February 2009 saw the worst fire weather conditions in the Australian state of Victoria's history. The maximum temperature in Melbourne's CBD was 46.4 degrees centigrade, with temperatures elsewhere up to 2.5 degrees higher than the previous record at that site (Karoly 2009). There were very strong winds, and record low relative humidity of 5% (although humidity data in Australia is limited) (Karoly 2009).

With climate change, such hot dry conditions are very likely to become more frequent. (See for example: Goldammer and Price, 1998; Kitzberger, Swetnam *et al.*, 2001; Flannigan, *et al.*, 2005; Reinhard, *et al.*, 2005; Hennessy, *et al.*, 2006; Moriondo, *et al.*, 2006). Alexander and Arblaster (2009) report increases in temperature extremes and a significant increase in the length of heatwaves in Australia over the period 1957-1999.

The day of the fires came after 12 years of the state's hottest and longest drought (Trewin and Vermont, 2010). Over this period, average annual rainfall was 10-13% below any previous twelve-year period (before 1997) and the rainfall total was 10-20 % below the long-term average (Royal Commission 2009, Chapter 1 footnote 5). There had been a string of the hottest years on record in the last decade, a 35 day dry spell with no measurable rain for Melbourne through January 2009, topped off by the most severe heatwave on record the week before (Trewin and Vermont, 2010). These antecedent conditions were likely, even in the absence of the extreme conditions on February 7, to result in non-linear effects in terms of enhanced conditions for wildfires (REF). The heat and drought resulted in very low fuel moisture content of about 3-5% on February 7. Under these conditions, any fuel will burn vigorously.[1] Fire weather severity is measured by the Fire Danger Index (FDI) which ranges from 0-100. On

February 7 the FDI was predicted to be well over 160 +. The actual index appears to have been as high as 189 or higher in some areas (Royal Commission 2009, Figure 1.6).

[INSERT FOOTNOTE 1 HERE: Fire energy is measured in watts per linear meter of fire front. Forest fires during February 7th reached intensities of 80,000 KWm-1 (Royal Commission 2009, Fig 1.6), similar to levels seen during the 1983 Ash Wednesday fires in Victoria (Packham 1992). Unless the fires are very small at less than a hectare, suppression action by direct attack has an upper limit around the 4kW m -1 in forest fuels (Luke and McArthur, 1978; Buckley 1994). The use of aerial fire fighting appliances has little impact on this figure (Rawson and Rees 1983, Loane and Gould 1986, Robertson et al 1997, McCarthy 2003, Royal Commission 2009, Fig 1.6). Asset protection may nevertheless be effective, and was effective for many on February 7 (REF).]

In addition to the 173 lives lost as a direct result of the fires (State of Victoria, 2009), losses included the destruction of over 2000 homes, losses of livestock and crops, damage to infrastructure, and business premises.

Like most major Australian cities, Melbourne is expanding into former farmland and bush areas, with little or no regard for the fire risk. This is complemented by a flow of people moving into rural areas. Regional Victoria is projected to grow by 400,000 people by 2031, mostly in coastal and inland areas near Melbourne and major regional centres (State of Victoria, 2005). Many of those moving into rural areas are in search of lifestyle changes (Burnley and Murphy, 2004; Costello, 2007), the bush environment, and housing affordability (Berry, 2003; Costello, 2009), with the latter likely to be the most powerful driver.

Under the climate conditions experienced in the area north of Melbourne ten years ago, the area was considered low fire risk (REF). However, the desiccation of formally mixed wet and dry sclerophyll forests and moist south facing slopes by the drought and heat changed the area into a high risk area (CITE). The increased exposure includes infrastructure, town centres and livelihoods, much of which was damaged or destroyed in the Melbourne fires. Significant essential infrastructure serving much of Melbourne is also located in or near the fire affected areas, including water supply catchments, electricity supply corridors and telecommunications facilities.

In addition to these fixed exposures, there is an increasing amount of transitory exposure due to people visiting the areas for recreation and tourism. The exposure of people can be changed rapidly by people, and their movable assets, moving into or out of the areas at risk.

A range of factors influenced people's *susceptibility to harm* from the Melbourne fires. Many people were not physically or psychologically well-prepared for the fires, and this influenced the level of loss and damage they incurred. Levels of physical and mental health also affected people's vulnerability. Many individuals with ongoing medical conditions, special needs or other impairments struggled to cope with the extreme heat and were reliant on others to respond safely (Whittaker *et al.*, 2009). *Capacity to recover* in a general sense is high for humans and human activities through insurance, government support, private donations, and NGOs.

Capacity is highly variable for natural ecosystems. Some areas show strong regrowth while others show little, demonstrating the impacts of very high intensity fires and ongoing drought. The long drought, habitat destruction through urban expansion and the spread of feral species had reduced ecosystem resilience in the fire affected areas.

______ END BOX 4-2 HERE _____

4.2.2.1. About Permafrost

Climate change in the Russian Arctic degrades permafrost, such that vast territories of tundra may be replaced by taiga. From epidemiological point of view these changes could expand the habitat of rodent species that carry infections. Changes in water circulation and rising water temperatures could also increase diseases in marine mammals and fish [Climate change impact . . .]. Climate warming leads to permafrost degradation, the 40-80-cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost (Sherstyukov, 2009). Changes in permafrost damage the foundations of buildings and disrupt the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10-12% in 20-25 years, with permafrost borders moving 150-200 km northeast (Anisimov *et al*., 2004).

An apartment building collapsed following melting permafrost in the upper stream of the Kolyma river, and over 300 buildings were severely damaged in Yakutsk as a result of retreating permafrost. More than 50% of buildings in Pevek, Anderm, Magadan, and Vorkuta have also been damaged [Anisimov, Belolutskaya, 2002, Anisimov, Lavrov, 2004]. Approximately 250 buildings in Norilsk industrial district had significant damage caused by deteriorating permafrost and approximately 40 apartment buildings have been torn down or slated for demolition [Grebenets, 2006.]. Permafrost degradation along the coast of the Kara Sea may lead to intensified coastal erosion, which moves the coastline back by 2-4 meters per year [Anisimov, Lavrov, 2004]. This coastline retreat poses considerable risks for coastal population centres in Yamal and Taymyr and on other littoral lowland areas. Climate refugees may emerge if climate change significantly damages housing. Refugees from climate change have already appeared in Arctic territories of the United States (Shishmaref) and Canada (Tuktyaktuk). Coastal destruction has also become a problem for residents of Inupiat and on the island of Sarichev.

4.2.2.2. Case Study – Forest Fires in Indonesia

Old-growth forests are usually carbon sinks. As old-growth forests steadily accumulate carbon for centuries, they contain vast quantities of it. They will lose much of this carbon to the atmosphere if they are disturbed, so carbon-accounting rules for forests should give credit for leaving old-growth forest intact (Luyssaert *et al*., 2008).

Severe drought in moist tropical forests provokes large carbon emissions by increasing forest flammability and tree mortality, and by suppressing tree growth (Ray *et al*., 2004). The frequency and severity of drought in the tropics may increase through stronger El Niño Southern Oscillation (ENSO) episodes, global warming, and rainfall inhibition by land use change (Ray *et al*., 2004).

Under drought conditions, fires in Indonesia is a disproportionate contributor to GHG from biomass burning, although human are igniting the fires, drought acts as trigger for fire occurrence and large fires events were found to occurred when precipitations drop below 609mm (Field *et al*., 2009). In Indonesia and PNG, formation of peatland during Holocene lead to the accumulation of potentially 70 Pg of carbon, this is comparable to the carbon stored in aboveground vegetation in the Amazon or to 9 years of contemporary global fossil fuel emissions. Drought episode, forest fires, drainage for rice fields and oil palm plantations are drying the peatlands which are then more vulnerable to fires (Van der Werf *et al*., 2008).

Over Amazonian forest, forest subjected to a 100-millimeter increase in water deficit lost 5.3 megagrams of aboveground biomass of carbon per hectare. The drought had a total biomass carbon impact of 1.2 to 1.6 petagrams (1.2 × 1015 to 1.6 × 1015 grams). Amazon forests therefore appear vulnerable to increasing moisture stress, with the potential for large carbon losses to exert feedback on climate change (Phillips *et al*., 2009).

If drought is a trigger to deforestation via forest fires, conversely, deforestation in the Amazon and Cerrado was found to increase the duration of the dry season in these regions (Costa and Pires, 2009).

A drastic deforestation scenario would result in a severe restructuring of land–atmosphere dynamics (see Figure 4-2), partially explaining why most AGCMs have predicted weakened water fluxes as a result of extensive deforestation (D'Almeida *et al*., 2007).

[INSERT FIGURE 4-2 HERE:
Figure 4-2: Schematic representation of the hydrological impact of different extents of clearing (in dark gray) in Amazonia. The horizontal water vapor flux transfers moisture into the region and in the case of (a) no deforestation, this flux is sustained by precipitation recycling, maintaining high indices of rainfall. Areas of (b) local deforestation are too small to affect rainfall, but runoff increases and evapotranspitation decreases. Areas of (c) regional

deforestation are large enough to influence circulation, strengthening convection and potentially increasing rainfall. A (d) basin-wide deforestation scenario would impose a severe decline on evapotranspiration and then on precipitation recycling, weakening the hydrological cycle in Amazonia as a whole. Source: (D'Almeida et al., 2007).]

In an inventory of over 225,000 trees of tropical forest in Panama, (Chave *et al*., 2003) conclude that small trees were providing much of the biomass increase, however 60% of the biomass is included in 1% of the larger diameter trees, while 97.6% of the smaller diameter trees include less than 15% of the biomass. In this view, slowing deforestation, combined with an increase in forestation and other management measures to improve forest ecosystem productivity, could conserve or sequester significant quantities of carbon (Dixon *et al*., 1994).

4.2.3. How Do They Impact on Humans and Ecosystems?

4.2.3.1. Concepts and Human Impacts

The impacts of weather and climate extremes on humans and ecosystems are a function of exposure, vulnerability and the type and magnitude of the climate extreme. Or put another way the impacts of weather and climate extremes are mediated by exposure and vulnerability. This is occurring in a context where all three components, the social and political elements of exposure and vulnerability, and the physical element of climate, are highly dynamic and subject to continuous change. For instance nowadays, a less extreme rain (compared with past records) may lead to a very serious flooding disaster. Reduced volumes of natural water storage – floodplains, wetlands; and increase in ground imperviousness and in runoff coefficient may cause higher river runoff corresponding to a given rainfall. Furthermore, the value of wealth accumulated in the affected area has grown as well.

Changes to exposure and vulnerability can be considered as adaptive action. For example, migration away from high hazard areas [hazard is here defined as the climate event following EMA and ISDR – cf Chapter 1] reduces exposure and the chance of disaster and is also an adaptation to increasing risk from climate extremes. Similar remarks could be made for changes to building regulations and livelihoods, among numerous other examples. However, in this chapter impacts are assessed without reference to possible adaptive action, and the chapter does not attempt to distinguish between adaptive action as a result of climate change and the management of exposure and vulnerability for existing hazards.

“Vulnerability” is defined here to mean susceptibility to harm and ability to recover (EMA, but cf Chapter 2). This chapter will also refer to “resilience” (developed in an ecological context by Holling, 1978; in a broad social sustainability context by Handmer and Dovers 2005; and by the Resilience Alliance, Adger, 2006), which emphasises the positive components of resistance or adaptability in the face of an event and ability to cope and recover. The language of “resilience” is often seen as a positive way of expressing a similar concept to that contained in the term “vulnerability” (Handmer, 2003).

4.2.3.2. Disaster

Extreme impacts on humans and ecosystems can be conceptualised as “disasters” or “emergencies”. Charles Fritz (1961: 655) was probably the first to articulate a definition in the research and policy literature: Disasters are “…uncontrollable events that are concentrated in time or space, in which a society undergoes severe danger and incurs such losses … that the social structure is disrupted and the fulfillment of all or some of the essential functions .. is prevented.”

Many contemporary definitions are similar, emphasising either that a disaster results when the impact is such that local capacity to cope is exceeded or that it severely disrupts normal activities. For example, the Center for Research on the Epidemiology of Disasters (CRED) in Brussels, Belgium has four criteria for a disaster including two suggesting external aid: “declaration of a state of emergency” and “call for international assistance”. The Australian Emergency Management Glossary emphasises disruption: “A serious disruption to *community* life which threatens or causes death or injury in that community and/or damage to property which is beyond the day-to-day capacity of the prescribed statutory authorities …" (EMA Glossary Manual 03 – 1998).

Despite the emphasis in official definitions, in practice:

> "Disasters are subject to numerous definitions: to an investment bank they mark an investment opportunity, in the same genre as investing in shares; they are research opportunities; and the livelihoods of many NGOs and professionals are built on them. To governments, disasters offer the opportunity to legitimise themselves, to parade their power by mobilising resources, and to empathise with the victims by offering sympathy and assistance. Seen like this, disasters are social, political or economic phenomena, not visitations by some force external to human control or as a result of calculated engineering risk" (Handmer and Dovers 2007).

Quarantelli (1998) examines this question from a variety of perspectives. There is a significant literature on the definitional issues which include factors of scale and irreversibility. Major issues with the standard definitions include:

- The focus on "events" which can obscure the social processes leading to disaster and also imply a definition framed by the natural event rather than by the impacts
- Reliance on "external assistance" which may discriminate against well prepared or otherwise resilient communities and sectors
- The idea of "returning to normal", as often it will not be possible to return to what was there before (Handmer and Hillman 2004), and it may not be desirable (REF)
- Some disasters may be difficult to define in space or time, droughts are an example, as are complex sequences of events referred to as complex unbounded problems (Handmer and Dovers 2007)
- As what constitutes or causes a disaster (or emergency) is dependent on a wide range of circumstances and varies greatly by location this chapter does not adopt a quantitative approach.

As stated at the start of this section, impacts require both exposure to the climate event and a susceptibility to harm by what is exposed.

Exposure can be conceptualised as human and ecosystem tangible and intangible assets and activities (including services) exposed (as in the way of) to the weather or climate event and its energy. Time and space scale is important. Exposure can be more or less permanent or transitory: for example, exposure can be increased by people visiting an area or decreased by evacuation of people and livestock after a warning. Exposure is a necessary but not sufficient condition for impacts. As human activity and settlements expand into a given area, more will be exposed to and affected by local climatic events. Most population increase is in poor countries that are disproportionately affected by climatic hazards. In addition, many newly occupied areas were previously left vacant precisely because they are hazardous, especially on the fringes of or in poorly-built infill in ever-growing urban areas. This is best seen in areas prone to flooding, landslides and industrial pollution, now occupied by squatters or informal settlements; and at the other end of the wealth spectrum, by those seeking environmental amenity through coastal canal estates, riverside and bush locations, areas that are often at greater risk from floods and fires.

For what is exposed to be subject to significant impacts from a climate event, there must be vulnerability. Vulnerability is composed of (i) susceptibility of what is exposed to harm (loss, damage) from the weather event, and (ii) its capacity to recover. For example, those whose livelihoods are weather dependent or whose housing offers limited protection from weather events will be particularly susceptible to harm, while those with limited capacity to recover include those with limited personal resources for recovery or with no access to external resources such insurance or aid after an event, and those with limited personal support networks. Knowledge, alternative livelihoods, health and access to services of all kinds including emergency services and political support help reduce both key aspects of vulnerability.

Refugees and those driven into marginal areas as a result of violence are often the most dramatic examples of people vulnerable to the negative effects of natural events, cut off from coping mechanisms and support networks (drawn from Handmer and Dovers 2007). Reasons for the increase in vulnerability associated with warfare include destruction or abandonment of infrastructure (transport, communications, health, education) and shelter, redirection of resources from social to military purposes, collapse of trade and commerce, abandonment of subsistence farmlands, lawlessness and disruption of social networks (Levy and Sidel 2000). The proliferation of weapons and minefields, the absence of basic health and education and collapse of livelihoods can ensure that the effects of war on vulnerability to disasters are long lasting. These areas are also characterized by an exodus of trained people and an absence of inward investment.

4.2.3.3. Impacts on Ecosystems

Even without considering the role of climate change, ecosystems are under significant threats. We are currently experiencing the sixth major biodiversity extinction and the first from human origins (Wilson, 1999). The current rate of species extinctions on Earth is 100 to 1,000 times greater than the natural rate and is accelerating (May et al., 1995)

Climate change will exacerbate the impacts from habitat fragmentation. Increased frequency of large-scale disturbances caused by extreme weather events will cause increasing gaps and an overall contraction of the distribution range, particularly in areas with relatively low levels of spatial cohesion (Opdam and Wascher, 2004). On the basis of mid-range climate-warming scenarios for 2050, 15–37% of species in their sample of regions and taxa will be ‘committed to extinction’ (Thomas, 2004). Rapid climatic change or extreme climatic events are expected to alter community composition. (Walther et al., 2002).

Extreme events can cause mass mortality of individuals and contribute significantly to determining which species occur in ecosystems (Parmesan et al., 2000). Drought plays an important role in forest dynamics, driving pulses of tree mortality in the Argentinean Andes (Villalba and Veblen, 1997), North American woodlands (Breshears and Allen, 2002; Breshears et al., 2005), and in the eastern Mediterranean (Körner et al., 2005b). Hurricanes can cause widespread mortality of wild organisms, and their aftermath may cause declines due to the loss of resources required for foraging and breeding (Wiley andWunderle, 1994). Greater storminess and higher return of extreme events will also alter disturbance regimes in coastal ecosystems, leading to changes in diversity and hence ecosystem functioning. Saltmarshes, mangroves and coral reefs are likely to be particularly vulnerable (e.g. Bertness and Ewanchuk, 2002; Hughes et al., 2003). [see also IPCC, AR4, GWII, 4.2.1]

Other anthropogenic changes are such as land use, nitrogen deposition, pollution and invasive species, habitat losses, and over harvesting (Vitousek et al., 1997; Mack et al., 2000; Sala et al., 2000; Hansen et al., 2001; Lelieveld et al., 2002; Körner, 2003b; Lambin et al., 2003; Reid et al., 2005; Wilson, 1999).

4.2.3.4. Phenomenon Induced by Climate Change that Lead to Impacts on Ecosystems

The impacts of change in frequency/intensity of extreme event are much less studied (Easterling et al., 2000), as most of the studies covers response to continuous climate change. Still, in the Northern Hemisphere the gradual northward and upward movement of the range of many species since 1904 is likely due to the effects of a few extreme weather events on population extinction rates (Parmesan, 2006). Extreme events have consequences which are difficult to predict, given that such situations may be unprecedented. The variations of the extreme events covers a large array, such as insect outbreaks, sudden and transient temperature changes, rapid retreat of sea- and lake ice, bouts of abnormally high precipitation or extended droughts, wildfires, the sudden release of water from melting glaciers, and slumping of permafrost are examples of stochastic events that may have disproportionately large effects on ecological dynamics (Post et al., 2009). Other factors inducted by climate change include “false springs,” and midsummer frost, which has been directly observed to cause extinction of species (Easterling et al., 2000).

In both the Canadian Rockies (Luckman, 1994) and European Alps (Bugmann and Pfister, 2000) extreme cold through a period of cold summers from 1696 to 1701 caused extensive tree mortality. Heat waves such as the recent 2003 event in Europe (Beniston, 2004; Schär et al., 2004) have both short-term and long-term implications for vegetation, particularly if accompanied by drought conditions. The December 1999 ‘storm-of-the-century’ that affected western and central Europe destroyed trees at a rate of up to ten times the background rate (Anonymous, 2001). Loss of habitat due to hurricanes can also lead to greater conflict with humans. For example, fruit bats

(*Pteropus spp.*) declined recently on American Samoa due to a combination of direct mortality events and increased hunting pressure (Craig et al., 1994). [see also IPCC, AR4, GWII, 4.2.1]

In Monteverde preserve (Costa Rica), 40% of the 50 local amphibian species have become extinct since 1983 (Easterling et al., 2000). A detailed analysis of four frog species showed that extinction followed a series of drastic population declines in each of three severe droughts associated with El Niño events (Easterling et al., 2000).

Climatic extremes appear to influence juvenile survival in large mammals species, primarily during winter (Milner et al., 1999). Single extreme temperature event influence the adult sex of turtle, as this is determined by the maximum temperature experienced by the growing embryo (J. J. Bull 1980 and F. J. Janzen 1994 cited in (Easterling et al., 2000).

Potential solutions

For species where no adaptation is possible, the only option is to mitigate the level of GHG released in the atmosphere so that Earth temperatures do not exceed the tolerance of the species.

For species which can migrate, reducing the impacts from climate change on species would request a shift in strategy from protected areas towards landscape networks including protected areas, connecting zones and intermediate landscapes. A static approach of establishing isolated reserves surrounded by a highly unnatural landscape is not an effective strategy under a climate change scenario (Opdam and Wascher, 2004).

4.2.4. Lists of Hazards in Terms of Hazards (Climate Extremes), Sectors and Systems, and Regions

[possible three-dimensional matrix maybe electronic as a product of the chapter]
[awaiting completion of other sections]

[INSERT TABLE 4-2 HERE:
Table 4-2: Factors to be considered in this section.]

4.2.5. Detection and Attribution of Climate Change Impacts *(also see Section 4.6.5)*

Detection and attribution of climate change impacts can be defined and used in way that parallels the well-developed applications for the physical climate system (IPCC 2010). Detection is the process of demonstrating that a system affected by climate has changed in some defined statistical sense, without providing a reason for that change (IPCC 2007). Attribution is the process of establishing the most likely causes, natural or anthropogenic, for the detected change with some defined level of confidence.

The IPCC Working Group II Fourth Assessment Report found, with very high confidence, that observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases (IPCC 2007). Further, data since 1970 shows that anthropogenic warming is likely (66-90% probability of occurrence) to have had a discernible influence on many physical and biological systems. Two fundamental approaches have been used in detection and attribution of climate change impacts: direct attribution and joint attribution.

Direct or 'single-step' attribution comprises assessments that attribute an observed change within a system to an external forcing based on explicitly modeling the response of the variable to external forcings and drivers (IPCC, 2010). Few such studies have been carried out and are limited to cases where the affected system and its interaction with climate are either relatively well modeled (e.g. hydrological cycle; Barnett et al., 2008) or reasonably described empirically (e.g. area burnt by forest fires; Gillett et al., 2004).

Joint or 'multi-step' attribution comprises assessments that attribute an observed change in a system to a change in climate or environmental conditions, and the change in climate or environmental conditions is separately attributed to external forcings and drivers (IPCC, 2010). Using this approach, changes within many physical (e.g. glaciers, river flow, coastal erosion) and biological systems (e.g. polar bear behavior, spring flowering, bird migration, grape harvests) have been linked to regional warming and, in turn, the warming attributed primarily to increasing anthropogenic greenhouse gas concentrations (Rosenzweig et al., 2008 and references therein).

In the case of weather and climate extremes and rare events, attribution to anthropogenic forcing is complicated by the fact that any such event might have occurred by chance in an unmodified climate. For example, a change in the frequency of rare heatwaves may not be detectable. A solution to this problem is to look at the risk of the event occurring, rather than the occurrence of the event itself (Stone and Allen, 2005). For example, human-induced changes in mean temperature have been shown to increase the likelihood of extreme heat waves (Stott et al., 2004).

There is considerable evidence that economic losses from weather-related disasters are increasing but reliably attributing these losses to climate change is proving difficult (Miller et al 2008). Some studies claim that a climate signal can be found in the records of disaster losses (Malmstadt et al., 2009; Schmidt et al., 2009). However, others argue that the increasing losses can largely be accounted for by underlying societal trends - demographic, economic, political, social - that shape our vulnerability to impacts (Pielke et al, 2005; Bouwer et al., 2007). Attempts have been made to normalize loss records for changes in exposure and vulnerability. This allows detection of observed changes in weather hazard rather than the disaster impact. In general, no long-term trends can be found in normalized losses due to extreme wind events (Pielke et al 2008; Miller et al 2008). Trends in flood losses can be explained largely by socio-economics drivers, including increasing occupancy of flood-prone areas and the increasing value of assets exposed to flood (Pielke and Downton, 2000; Barredo, 2009). However, other studies point to increased incidence of extreme precipitation as a potential cause (Changnon, 2009; Chang et al., 2009).

There is no conclusive evidence that anthropogenic climate change has lead to increasing losses, and increasing exposure of people and economic assets is most likely the major cause of the long-term changes in economic disaster losses. This conclusion depends on the processes used to normalize loss data over time. Different studies use different approaches to normalisation, and to handling variations in the quality and completeness of longitudinal loss data. These are areas of potential weakness in the conclusions of longitudinal loss studies and need more empirical and conceptual effort. A second area of uncertainty concerns the impacts of modest weather and climate events on the livelihoods and people of informal settlements and economic sectors, especially in developing countries. These impacts have not been systematically documented with the result that they are largely excluded from longitudinal impact analysis.

4.2.6. Comment on 4°C Rise

A 4°C rise in itself is not an extreme event, but it may result in much more significant change in frequency/magnitude of various extreme events than climate change of around 2 degrees. Since some studies (ex. Betts et al. (2009)) suggest that the likelihood of a 4°C rise in latter half of this century is not negligible, we also need to be prepared for these significant changes. Knowledge of impacts expected under +4°C world and of response strategies to such impacts have been emerging recently.

The international climate policy target of the community (cf. Copenhagen Accord, 2009) is to restrict global warming to less than 2°C. This level is often held as a relatively safe limit beyond which the humans should not pass, even if already a 2 ºC warming brings risks to unique and threatened systems, risks of extreme events, and distribution of impacts (cf. IPCC TAR SPM, Schneider, 2009). The ‘burning embers’ diagram (see Figure 4-3) illustrates the reasons for concern and urgency of threats as a function of temperature. In order to achieve this goal, major, and effective, global mitigation efforts would be required, which should start sufficiently early (Hulme and Neufeldt, 2010).

[INSERT FIGURE 4-3 HERE:
Figure 4-3: Burning embers (Schneider, 2009).]

The Intergovernmental Panel on Climate Change assessed five reasons for concern in terms of societal, economic and natural damage that would be caused by climate change (TAR, 2001). Updates to judgements about the thresholds at which such damages might occur revised the thresholds downwards Smith et al., 2009).

Impacts can be related to global mean temperature increase and the risks of large adverse changes and the reasons for concern greatly increase for higher levels of temperature increase (TAR, AR4, Schneider, 2009; see Figures 4-4 and 4-5). A scenario without effective mitigation (business-as-usual), can be symbolically denoted as 4°C warming. This entails high risk in all categories of reasons for concern, including risk of extreme weather events, distribution of impacts, the aggregate economic impacts and the risk of large-scale continuities. A 4°C warming may lead to dangerous effects of climate change in the context of Article 2 of the UN FCCC.

[INSERT FIGURE 4-4 HERE:
Figure 4-4: Illustrative examples of global impacts projected for climate changes (and sea-level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts, dotted arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left hand side of text indicates approximate onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of Special Report on Scenarios (SRES) scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. (Source: IPCC AR4 WG2 SPM, 2007).]

[INSERT FIGURE 4-5 HERE:
Figure 4-5: Illustrative examples of global impacts projected for climate change (Stern, 2006).]

An illustration of impacts of 4°C warming is the average global number of people affected by 100-year floods per year evaluated as 544 million, i.e. over 2.5 times more than for 2°C warming (projected to be 211 million), cf Hirabayashi and Kanae (2009) and Kundzewicz et al. (2010).

According to Arnell (2009), 15% of land worldwide that is currently suitable for agriculture would become unproductive at a +4°C world. On the other hand, suitable land would shift north, to regions such as Siberia, which is currently covered in forest. Globally, extension of suitable area for crop production is larger than loss of present suitable area even with climate change of 4°C warming. However, regarding regional impacts, extension of suitable area for crop production cannot be expected even with small degree of climate change in Southern and Eastern Africa while loss of present suitable area will monotonically increase and reach more than 30 % at +4°C world.

Rahmstorf (2009), employing a semi-empirical approach he has developed, projected future sea level rise of 1 – 1.3 meters at 4 ºC above preindustrial temperatures by 2100, much higher than the projected sea level rises reviewed in IPCC-AR4.

Adaptation to 4°C warming, globally, would be very difficult and costly, and many adverse effects cannot be avoided. Projections of impacts and adaptation for a number of sectors and systems show that effective climate policy combines mitigation and adaptation, in order to constrain adverse impacts at a manageable level (Hulme and Neufeldt, 2010).

4.3. Observed Trends in Exposure and Vulnerability

4.3.1. Climate Change Contributes to and Exacerbates Other Trends

On the global scale, annual material damage from large weather events has increased 8-fold between 1960s and 1990s, while the insured damage has risen even stronger (17-fold in the same interval), in inflation-adjusted monetary units. Material damages caused by natural disasters, mostly weather and water-related have increased more rapidly than population or economic growth, so that these factors alone may not fully explain the observed increase in damage. The loss of life has been brought down considerably (Mills, 2005).

The drought and flood losses may have grown due to a number of non-climatic factors, such as increasing water withdrawals effectively exacerbating the impact of droughts, decrease in storage capacity in catchments (urbanization, deforestation, sealing surfaces, channelization) adversely affecting both flood and drought preparedness, increase in runoff coefficient, and mushrooming settlements in floodplains around urban areas.

On average, 2% of agricultural land has been lost to urbanization per decade in the European Union. Van der Ploeg et al. (2002) attributed the increase in flood hazard in Germany to climate (wetter winters), engineering modifications, but also to intensification of agriculture, large-scale farm consolidation, subsoil compaction, and urbanization. The urbanized area in West Germany more than doubled in the second half of 20th century.

Since water resources have always been distributed unevenly in space and time, people have tried to reduce this unevenness and smoothen the spatial–temporal variability. Regulating flow in time can be achieved by storage reservoirs, capturing water when abundant and releasing it when it is scarce, while regulating flow in space can be achieved via water transfer. Dams and reservoirs have been built for millennia, but most large dams have been constructed since the second half of the twentieth century. Now, the total volume of reservoirs exceeds 6000 km^3, whereas the total water surface area reaches 500 000 km^2. In result of dams and reservoirs, the natural runoff regime of many rivers has been considerably altered (cf. Vörösmarty, 2002).

Until a century ago, when the number of people on Earth was relatively low, and the human impact on water resources (using and drinking freshwater) was generally insignificant, and local rather than global in impact. The situation dramatically changed as water withdrawals strongly increased due to dynamic population growth (from 1.65 billion in 1900 to 2.56 billion in 1950 and 6 billion in 1999, and 7 billion in 2010) and socioeconomic development driving improvements in living standards, including more water-intense diet and improving hygiene. Freshwater, which is a necessary condition of life and a raw material used in very high volumes in virtually every human activity, has become increasingly scarce in many places and times. Water use has risen considerably in the past hundred years, at a pace twice as fast as the relative population growth (Kundzewicz, 2008). There has been a dramatic expansion of water demands (and water withdrawals) for food production, hygiene and human well-being, and industry, including by the power sector. This exacerbated the severity of droughts and societal vulnerability to droughts and water deficits.

In much of the developed world, the societies are ageing, hence more sensitive to weather extremes, such as heat wave.

It is now reasonable to assume that climate stationarity does not exist, and the past is not really a key to the future, as we are entering a situation with no analogy in past records (Milly et al., 2008). This is of vast importance for design rules. What used to be a 100-year river flow (exceedance probability of 0.01) is projected to be exceeded less frequently over some areas and more frequently over other areas. In the latter case, if the existing defences are designed for a 100-year flood, they do not have to be strengthened in order to maintain the same level of protection. However, in the areas where the level of past 100-year flood is projected to be exceed more frequently (e.g. every 50 years, on average), there will be a need to strengthen and heighten the existing protection system, in order to maintain the same protection level (Kundzewicz et al., 2010).

*4.3.2. **Observed Trends in Exposure** (demographic, to all climatic extremes, and to specific types of hazard)*

4.3.2.1. Human Exposure to Tropical Cyclones by Region

Description

These figures are extracted from the PREVIEW Global Risk Data Platform (PREVIEW, 2009), methodologies and extract of the data were published in the Chapter 2 of the UNISDR 2009 Global Assessment Report (Peduzzi, 2009). These figures are taking only the hazard exposure assuming constant hazard. We will need to review these figures, once we receive the inputs from SREX Chapter 3 team on the envisaged increase of intensity/frequency of the hazards.

4.3.2.1.1. Exposure for tropical cyclones by region and by class of intensity

The figures are yearly average human exposure (computed over 32 years) to tropical cyclones winds by Saffir-Simpson classes. Total yearly average human exposure to tropical cyclones in 1970, 1990 and 2010 is of respectively 45, 62 and 77 millions. This is due to increase in population living in exposed areas and assuming hazard is constant. With change in intensities (and or) frequencies of the cyclones, these figures will probably change in the future. Details of exposure by class of Saffir-Simpson and year are provided in the three tables below for 1970, 1990 and 2010.

[INSERT TABLE 4-3 HERE:
Table 4-3: Yearly average human exposure to tropical cyclones in 1970 (Peduzzi et al., 2009).]

[INSERT TABLE 4-4 HERE:
Table 4-4: Yearly average human exposure to tropical cyclones in 1990 (Peduzzi et al., 2009).]

[INSERT TABLE 4-5 HERE:
Table 4-5. Yearly average human exposure to tropical cyclones in 2010 (Peduzzi et al., 2009).]

This could be presented as graphs or maps, however, we will wait for final figures on hazards changes to produce the graphs. GDP exposure is also available.

4.3.2.1.2. Exposure for floods by region

Only catchment areas bigger than 1000 km^2 are considered in this analysis (Peduzzi *et al.*, 2009).

[INSERT TABLE 4-6 HERE:
Table 4-6: Yearly average human exposure to floods in 1970, 1990, and 2010 (Peduzzi et al., 2009).]

4.3.3. Observed and Projected Trends in Hazards and impacts, Changing Frequency of Different Intensities, and New Locations Affected *(to be discussed with Chapter 3)*

4.3.3.1. Coastal Systems: Natural and Human

Coastal systems are among the world's most vulnerable areas to climate extremes. Superimposed upon the intrinsic long-term trends of coastal systems (due e.g. to tectonic movements (Vött, 2007) or sediment auto-compaction (Massey et al., 2006)), are impacts by both marine (e.g. sea level rise, storm surges and waves) and terrestrial (e.g. precipitation/run-off) extremes of increasing frequency and intensity extremes (e.g. Lozano et al., 2004; Wang et al., 2008; The Copenhagen Diagnosis, 2009; Steffen, 2009; Fiore et al., 2009; Ruggiero et al., 2010), the effects of which on the system morpho-sedimentary dynamics are controlled by inherent environmental change thresholds (Nicholls et al., 2007). Moreover, as the size/permanence of coastal communities and infrastructure has increased very significantly over recent decades, the ability of coastal systems to respond has decreased; thus the exposure of coastal communities/assets has increased (Lenton et al., 2009). Although predictions of exposure to climatic extremes are required at decadal to century scales (e.g. Viles and Goudie, 2003), most of the available data/models are based on studies at either millennium (e.g. Masters, 2006; Nott et al, 2009) or annual (e.g. Quartel et al., 2008; Greenwood and Orford, 2008) or even storm event (e.g. Callaghan et al., 2008) scales. There have been several attempts to develop global coastal hazards data bases (Gornitz, 1991; Vafeidis et al., 2008), as well as methodologies/tools to assess the vulnerability of coastal systems to sea level rise/extreme events (e.g. Bernier et al., 2007; Purvis et al. 2008; Hinkel and Klein, 2009), but further work is urgently required (Nicholls et al., 2007). Coasts comprise several sedimentary environments and landforms, such as beaches, seacliffs, deltas, back-barrier environments (estuaries and lagoons), saltmarshes and mangroves, seagrass meadows and coral reefs. Each of these environments is characterised by different vulnerability to climate change-driven hazards (Table 4-7).

[INSERT TABLE 4-7 HERE:
Table 4-7: Coastal systems: summary table of observed and predicted exposure trends.]

4.3.3.1.1. Natural systems [to be shifted to Chapter 3?]

Beaches and seacliffs

Beaches, i.e. the low-lying coasts built on unconsolidated sediments, are among the most morphologically dynamic environments, being controlled by complex process-response mechanisms that operate in several temporal and spatial scales (Van Rijn, 2003). Beaches provide dynamic protection to the coastal environments they front (e.g. back-barrier systems and cliffs), as well as an increasing human infrastructure and other economic assets. Beach erosion can be differentiated into: (i) long-term erosion, i.e. irreversible retreat of the shoreline position, due to sea level rise and/or negative coastal sedimentary budgets (Nicholls et al, 2007) that force either landward migration of the beaches or drowning; and (ii) short-term erosion, caused by storms and storm surges, which may not necessarily result in permanent shoreline retreats, but may create large-scale devastation (Niedoroda et al., 2009). Beach erosion is already a major global problem, being very significant along the southeastern (Zhang et al., 2004), the Gulf (Morton et al., 2004) and California (Hapke et al., 2006) US coasts, in China (Cai et al., 2009), in India (Dwarakish et al., 2009), in Canada (Forbes et al., 2004; Lantuit and Pollard, 2008), the Pacific island atolls (Dickinson, 2004), the Atlantic, Mediterranean and Baltic European coasts (Eurosion, 2004) and the Black Sea (Stanica and Panin, 2009). The projected sea-level rise (SLR) (IPCC, 2007; Rahmstorf, 2007; Richardson et al., 2009) will likely exacerbate beach erosion (Velegrakis et al., 2009), although the local timing and extent of beach morphological response will depend also on other factors, such as the beach and inner continental shelf physiography (Callaghan et al., 2008), the ‘normal’ and storm coastal hydrodynamics and sediment dynamics (Stockdon et al., 2007; Pye and Blott, 2008; Nott et al., 2009), the coastal sediment availability and budgets (Battiau-Queney et al., 2003; Dan et al., 2009) and the presence of adjacent back-barrier sediment traps (Nicholls et al., 2007); these factors can significantly modify beach response to sea level rise. In addition, changes in the intensity and/or frequency of storms (see Section 3.4 and e.g. Ruggiero et al., 2010) and/or other climatic extremes such as heavy precipitation events and river floods (e.g. The Copenhagen Diagnosis, 2009) may be even more important than sea level rise in determining future beach morphodynamics (e.g. Brunel and Sabatier, 2009; Barnard and Warrick, 2010)). Finally, large climatic modulations (e.g. ENSO and NAO), may also have significant impacts, as they promote larger frequency of high energy events (Nicholls et al., 2007).

Seacliff erosion, which may have significant socio-economic impacts (Del Río and Gracia, 2009), can usually be attributed to extreme events, being controlled by both storm surges and storm wave attack (Sallenger et al., 2002; Hall et al., 2008), as well as strong rainfall (Greenwood and Orford, 2008; Young et al., 2009). Erosional processes appear to be dependent on the cliff lithology and geotechnical properties (Collins and Sitar, 2008), the characteristics (height and steepness) of the storm waves (Hansom et al., 2008), as well as the volume of fronting protecting beaches (Walkden and Dickson, 2008); modeling experiments have shown that seacliff retreat will be exacerbated by sea level rise (Nicholls et al., 2007).

Deltas

Deltaic environments are influenced by all climatic changes/extremes affecting riverine and marine processes (e.g. changes in the precipitation/run-off, sea level rise and storms), as they are controlled by the combined action of riverine, wave and tidal processes (Restrepo and Lópe, 2008; Poulos et al., 2009). In addition, deltas are commonly impacted by the effects of human development, such as sediment starvation due to river management schemes and engineering works at their mouths (Stanica et al., 2007; Mikhailov and Mikhailova, 2008; Simeoni and Corbau, 2009), which may affect significantly the exposure and resilience of the deltaic coasts to climatic changes (Sabatier et al., 2009). Deltas are particularly sensitive to climate change, as they are commonly characterized by large Relative Sea Level Rise (RSLR) due to the combination of eustatic sea-level rise, deltaic sediment auto-compaction, groundwater/hydrocarbon extraction-induced subsidence and diminished sediment supply. A study involving 40 deltas, representing all major climate zones and which collectively drain 30% of the Earth's landmass and 42% of global terrestrial runoff has found RSLRs ranging between 0.5 to 12.5 mm yr^{-1}, with the diminishing fluvial sediment supply/deposition being the most important determinant of the result (Erickson et al., 2006). Extreme events, particularly storm surges (Ullmann et al., 2007; McKee Smith et al, 2010) pose a particular threat to deltaic environments, especially the larger systems which are considered as hotspots of vulnerability (Coleman et al., 2005; Nicholls et al., 2007).

Estuaries and lagoons

Estuaries and lagoons are particularly sensitive systems to climate change. Climate-driven changes and extreme events with regard to freshwater run off can affect water residence time, nutrient delivery, stratification, salinity and primary productivity (Nicholls et al., 2007; Gamito et al., 2010). Sea-level rise generally translates into landward transgression of estuaries (Pethic, 2001) and leads to higher relative water levels and salinity, affecting hydrodynamics (Simionato et al., 2004) and sediment dynamics (Shennan et al., 2003), the distribution of tidal wetlands (Doyle et all, 2009) and biodiversity (Ellison, 2005). Water level changes can increase the risk of flooding, particularly if combined with high river flows, storm surges, and the effects of water management schemes (Le et al., 2007). Increases in the intensity of tropical cyclones and other storms combined with sea level rise, are likely to increase substantially the exposure to flooding (Karim and Mimura, 2008), as well as alter estuarine sediment dynamics and biogeochemical processes (Paerl et al., 2001). With regard to human-induced changes, it has been shown that their effects on estuarine morphodynamics can, in some cases, be greater than those of the sea level rise itself (Chust et al., 2009), although modeling exercises suggest that, in the long term, the morphological development will be mostly controlled by the estuarine physiography and the ability of external sediment supply to meet the increasing sediment demand of the system (Reeve and Karunarathna, 2009).

Coastal wetlands, coral reefs and seagrasses

Coastal wetlands (saltmarshes, mangroves) are controlled by long-term sea-level changes. Modelling of coastal wetlands (McFadden et al., 2007) indicates large global losses by 2080, depending on the rate of sea level rise, wetland losses are likely to be most severe in micro-tidal and/or sediment starved coasts, as wetlands in meso- and macro-tidal settings and/or in areas with increased sedimentary inputs are considered to be better equipped to deal with changes in sea level (Cahoon et al., 2006). At the same time, as wetlands have the potential to attenuate storm surges and waves (Neumeier and Amos, 2006; Wamsley et al., 2010), their loss will probably result in further increase in storm surge and wave exposure.

Saltmarshes are common features of temperate coastlines; they are graded landward from salt, to brackish, to freshwater assemblages. Climate change will force changes in the hydrological, hydrodynamic and sediment dynamic regime, the frequency/intensity of extreme events and the biogeochemical conditions, with the effects considered to be more pronounced in brackish and freshwater marshes, (Nicholls et al., 2007). Saltmarshes accrete both organic and inorganic sediments. While feedbacks between vegetation growth and sediment deposition tend to promote morphological equilibrium under constant sea level rise rates, recent observations/modeling suggest that changes in the rise rates may induce marshland losses; it has been demonstrated that organic sediment accumulation is non-linearly related to both inorganic sediment supply and sea-level rise rates and that carbon accumulation increases with the rise rate until a critical threshold, which terminates the process and forces marsh drowning (Mudd et al., 2009). In addition, climatically-driven groundwater level fluctuations can also affect saltmarsh elevation and resilience (Cahoon et al., 2010). Simulation of the saltmarsh response to future rise in sea levels (100 year predictions) suggests that under low sea level rise scenarios, there may be marsh progradation, whereas under rapid rise rates vegetation zones are likely to transgress landward (Kirwan and Murray, 2008). With regard to the effects of storm surges and waves, accretion rates in micro-tidal, wave dominated marshes have been found to respond to short-term sea level changes, whereas those in macro-tidal, wave protected coasts mostly to long-term changes (Kolker et al., 2009). Finally, the propagation of surges and the impinging wave energy onto saltmarsh areas during storms have been found to be sensitive to sea level, with both surge propagation and wave heights being greater in areas with increased RSLR (McKee Smith et al., 2010).

Mangrove forests, found in sub-tropical and tropical coasts, may show both positive and negative responses to climate change, depending on site-specific factors (Saenger, 2002). Based on the available evidence, relative sea level rise may be the greatest threat to mangroves, as most mangrove sediment surface elevations do not appear to be able to keep pace (Gilman et al., 2008). Although mangrove accretion rates can be much higher than the average global sea level rise rates (commonly up to 5 mm/yr, see Saenger, 2002), mangal coasts are generally characterized by relatively rapid RSLR (Cahoon et al., 2003); this may result in either a mangrove transgression onto adjacent wetlands, as is the case in the US Gulf coast (Doyle et al., 2009) and southeast Australia (Rogers et al., 2005), or drowning and/or die-offs (Williams et al., 2003; van Soelen et al., 2010). Precipitation/run off has also been shown to be a significant factor, with a significant positive relationship found with landward mangrove expansion (Eslami-Andargoli et al., 2009). Finally, strong tropical cyclones can have negative effects on both the sedimentary structure (Cahoon et al., 2003) and the spatial distribution of mangroves (Paling et al., 2008).

Coral reefs are subject to a variety of impacts in relation to climate change (James and Crabbe, 2008) and, above some critical thresholds, they could be subjected to increased strain, or even collapse ((Veron et al., 2009), introducing particular concerns for the fate of small islands on the rim of atolls (Dickinson, 2004; Nicholls et al., 2007). Sea level rise itself appears to present a minor threat to coral reefs, as they have been found to be able to adapt effectively if not subjected to other environmental stresses (Hallock, 2005). Tropical cyclones and high energy storms, however, can inhibit typical reef growth (Montagionni, 2005) by decreasing coral recruitment (James et al., 2008) and/or result in reef destruction (Yu et al., 2004; Lugo-Fernandez and Gravois, 2010) with the reef debris deposited as reef talus at their lee (Harris and Heap, 2009) or as ridges to adjacent beaches (Nott and Hayne, 2001; Woodroffe, 2008). Other climatically-driven changes to the hydrodynamic regime of coral reef platform islands, such as changes in the direction of storm wave approach, may also result in significant morphological changes of the coral reef-beach systems (Kench et al., 2009).

Seagrasses appear to be in decline in many coastal areas, due mainly to human-induced interferences (e.g. seagrass bed removal for tourism purposes, see Daby, 2003), with the situation expected to deteriorate further due to climate-forced changes in the salinity and temperature of coastal waters, sea levels, atmospheric and dissolved CO2 concentrations and ultraviolet irradiance (Short and Neckles, 1999). Changes in coastal sediment dynamics can also affect seagrasses; studies on the effects of sediment deposition/erosion on shoot mortality, plant size, growth, biomass and density have shown species- and size-dependent sediment burial or erosion thresholds (Cabaço et al., 2008). Extreme precipitation and/or heat events (floods, droughts and heat waves) have also been observed to affect estuarine seagrass ecology (Cardoso et al., 2008). Finally, tropical cyclones can also affect the community structure of seagrass meadows, with the effects dependent on growth-form; solid, deeply anchored root–rhizomes or rhizoid systems, combined with a flexible or modular above-ground structure have been found to better resist perturbations by hurricanes and storms (Cruz-Palacios and van Tussenbroek, 2005).

4.3.3.1.2. Human systems

Although coastal inundation due to SLR (and/or RSLR) will certainly be a very significant problem for coastal landforms and coastal populations, activities, infrastructure and assets in Low Elevation Coastal Zones (LECZs, i.e. coastal areas with an elevation less than 10 m above present MSL, see McGranahan et al., 2007), the most devastating impacts are likely to be associated with extreme sea levels due to tropical and extra-tropical storms (e.g. Ebersole et al., 2010), which will be superimposed upon the long-term SLR. The impacts are considered to be more severe for deltas, coastal wetlands and Small Island States (Love et al., 2009), as well as large urban centers at the low end of the international income distribution (Dasgupta et al., 2009). The extent/distribution of exposure in each particular coastal area/urban center will be controlled by the intrinsic natural characteristics of the system (e.g. the occurrence/distribution of coastal wetlands that may attenuate surges, see Wamsley et al., 2010) or human-induced changes such as land reclamation (Guo et al., 2009).

With regard to the economic impacts of extreme events on coastal areas, a recent study by Nicholls et al. (2008) has assessed the asset exposure of 136 port cities with more than one million inhabitants (in 2005). They demonstrated that large population segments are already exposed to coastal inundation (~40 million people or 0.6% of the global population) due to a 1-in-100-year extreme event, while the total value of exposed assets was estimated as 3,000 billion US dollars (~ 5% of the global GDP in 2005). By the 2070s, population exposure was estimated to triple, whereas asset exposure could grow tenfold to ~ 35,000 billion US dollars, with the exposure growth being more rapid in developing countries; these estimations, however, do not account for the potential construction of effective coastal protection schemes. Lenton et al. (2009), who included tipping point scenarios, such as the effects of the partial collapse of the Greenland and West Antarctic Ice Sheets (Rahmstorf, 2007; Richardson et al., 2009), estimated a significant increase, by 2050, in the asset exposure in the same 136 port megacities to ~28,200 billion

US dollars. They also estimated a very substantial increase in the exposure of coastal population to inundation (see Table 4-8).

[INSERT TABLE 4-8 HERE:
Table 4-8: Current and future population exposure in low elevation coastal zones.]

One of the most significant effects of climate change driven extreme events on the infrastructure/services in coastal areas will be associated with transportation and especially with ports, key-nodes in international supply-chains; this may have far-reaching implications for international trade, as more than 80% of global trade in goods (by volume) is carried by sea (UNCTAD 2009a). Transportation will be affected by extremes in temperature and precipitation, storm surges and rising sea levels; while all modes of transportation are vulnerable, exposure and impacts will vary, e.g. by region, mode of transportation, as well as location/elevation and condition of any transport infrastructure (National Research Council, 2008; UNCTAD, 2009b). Coastal inundation may damage terminals, intermodal facilities, freight villages, storage areas and cargo and disrupt intermodal supply chains and transport connectivity (see Figure 4-6). These effects would be of particular concern to Small Island Developing States (SIDS), whose transportation facilities are almost all located in the LECZ (UNCTAD, 2009b; for further examples, see Love et. al. (2009)). One of the most detailed studies on the potential impacts of climate change on transportation systems was carried out in the US Gulf Coast. According to the study, RSLR of ~1.2 m could permanently inundate more than 2,400 miles of roadway, over 70% of port facilities, 9% of the rail miles operated and 3 airports, while more than 50% of interstate and arterial roads, 98% of port facilities, 33% of rail miles operated and 22 airports in the US Gulf coast would be affected by a ~5.4 m storm surge (CCSP, 2008). Experts at a recent UNCTAD Èxpert meeting highlighted the need for an increased focus on responding to the challenges posed by climate change, and the development of appropriate adaptation responses (UNCTAD 2009b). It should be noted that the International Association of Ports and Harbours (IAPH), representing some 230 ports in about 90 countries which handle over 60% of the world's sea-borne trade and nearly 90% of the world's container traffic has recently tasked its Port Planning and Development Committee to undertake the necessary studies (IAPH, 2009).

[INSERT FIGURE 4-6 HERE:
Figure 4-6: Freight handling port facilities at risk from storm surge of 5.5 and 7.0 m in the U.S. Gulf coast (CCSP, 2008).]

Housing in coastal areas will also be severely affected by climate change-driven extremes (e.g. Maunsell, 2008). A recent study (Lloyd's, 2008) has considered flood risk for coastal properties at a number of locations around the world due to SLR and storm surges and, at one location, changes in land use. The case-studies suggest that unless adaptation measures are taken, a 0.3 m sea level change could significantly increase the average loss exposure of high-risk coastal properties, even in coastal areas with well-maintained flood-defenses.

Tourism has, over recent years, increasingly become synonymous with beaches ((Phillips and Jones, 2006), a coastal landform that is under an increasing threat of erosion (see Section 1); island/archipelago destinations, one of the main focuses of the "sun and beach" mass tourism, are going to be particularly exposed to erosion (Bardolet and Sheldon, 2008; Schleupner, 2008). In addition to beach erosion, inundation of tourist infrastructure in coastal areas due to climate extremes (e.g. Snoussi et al., 2008; Dwarakish et al., 2009), salinization of the groundwater resources due to RSLR, land reclamation and overexploitation of coastal aquifers (e.g. Alpa, 2009) as well as changing weather patterns (Hein et al., 2009) will pose additional stresses to the industry. There are also expected to be shocks relating to tourist flow changes due to adjustments in consumption preferences, as well as regional income reallocation; these shocks are predicted to affect regional economies and lead to unevenly-distributed economic losses (Berrittella et al., 2006). Nevertheless, the potential impacts on the tourist industry will depend also on tourists' perceptions of the coastal destinations (e.g. of destinations experiencing beach erosion) which, however, can not be easily predicted (Buzinde et al., 2009).

4.3.3.2. Case Study – Long-Term Records of Flooding in Western Mediterranean [move to Chapter 3?]

In Mediterranean countries, flooding episodes and prolonged periods of drought constitute normal hydrological phenomena that society has to cope with. Floods are the natural risk with the greatest economic and social impact that can be generated in a short space of time (hours or days), although, if we are dealing solely with economic losses, drought impact in crops and losses in hydroelectric power generation can lead to higher economic costs (Pujadas, 2002). Flood and drought damages in Europe have been rising since 1980s despite of flood protection structures in rivers and flow regulation by dams (Munich Re, 2001). In addition, recent catastrophic floods have eventually became the largest events on the systematic record (most river flow measurements recording less than 50-60 years), being interpreted as a result of climate change. Documentary and palaeoflood (sedimentological and botanical) archives can provide a century-to-millennia reference of flood response (magnitude and frequency) to climate variability, from which interpreted recent and projected flood hazards. Moreover, long-term records provides a suite of examples about society coping with floods impacts from which learn to modify and adapt societal behaviours, and reasonable hypothesis for flood hazards to be expected for the next fifty years.

In terms of flood-producing atmospheric conditions, the western Mediterranean shows three distinct regions: (1) Central and Western Iberian Peninsula, (2) Mediterranean coast of Spain and Western Mediterranean Sea; (3) Corsica, Sardinia and the western coast of Italy (Douguédroit and Norrant, 2003). Central and Western Iberian Peninsula rivers respond to winter floods produced by Atlantic cyclonic systems brought by zonal circulation, highly correlated with winter (DJF) negative mode of the North Atlantic Oscillation (NAO) index (Trigo *et al.*, 2004). The Tagus river (Central-western Iberian Peninsula) documentary and palaeoflood (geological) records show an abnormally high frequency of large floods during distinct periods, namely at 1150-1290 1590-1610, 1730-1760, 1780-1810, 1870-1900, 1930-1950 and 1960-1980 (Benito *et al.*, 2003a,b; see Figure 4-7). Flood discharge estimates show that the largest floods happened in the 12-13th Century, late 19th Century and 20th Century periods. The largest historical flood peak discharges since AD 1500 (Benito *et al.*, 2003, 2008) occurred during negative winter (DJF) North Atlantic Oscillation index, as reconstructed by Luterbacher *et al.*, (2002). In large Iberian Atlantic rivers, flow regulation by dams since 1950s have decreased the frequency for floods of discharge less than 10-year return intervals (<8,000 m^3s^{-1}), but events of higher return intervals have occurred with a similar frequency (if not higher) than historical records (e.g. 1978, 1979, 1989, 1996, and 1998 floods). Decreasing risk perception on annual to decadal floods have led to occupation and urbanization of former inundation areas, with the subsequent increase on damages by multidecadal floods, producing important social and economical impacts in the Lisbon region. Climate model simulations suggest that NAO shows a weak positive response to increasing amounts of carbon dioxide, although none of the models are able to reproduce decadal trends as strong as observed in NAO index from 1970–1995 (Osborn, 2004; Stephenson *et al.*, 2006). Therefore, flood hazard projection on rivers highly correlated with NAO index remains still highly uncertain, although recent occurrence of large floods point out to be maintained over the next decades (Benito et al., 2005).

[INSERT FIGURE 4-7 HERE:
Figure 4-7: Temporal distribution of frequency of large floods.]

Flooding in the Mediterranean coast of Spain and France is associated with heavy rainfall induced by mesoscale convective systems (MCSs), and typically occurs during autumn months (SON). Flood records over the last 500 years show an intense climatic variability, characterised by periods of increased frequency of torrential rains, reflected in catastrophic flooding, as well as by an increased frequency of prolonged droughts (flood-rich and flood-poor periods). This abnormal behaviour usually lasted for 30 or 40 years (see Figure 4-7), being the periods of 1580-1620 and 1840-1870 the ones where the highest flooding severity was registered (Barriendos and Martín Vide, 1998). It appears that these periods recorded more frequent floods as compared to the 20th Century (Guilbert, 1994; Coeur, 2003, Luterbacher *et al.*, 2006), although similar extreme peak discharges were attained in some rivers by 20th Century floods. These recent catastrophic floods were ranked as the largest peak discharge but extended flow records from documentary and palaeoflood data over the last millennia shows a repeated past occurrence of such extreme floods (e.g. 2002-flood in Gardon river, Sheffer et al., 2008; 1973-flood in the Guadalentín-Segura basin Benito et al., 2009; and 1971-flood in the Llobregat River, Thorndycraft et al., 2005, 2006; and 1982-flood in Segre River, Thorndycraft et al., 2005). There is, however, an important and rising factor of vulnerability in most Mediterranean rivers, mainly cause by urbanization, and increasing sensitivity to natural hazards of modern society, that makes historic floods a highly destructive and intolerable modern flood hazard. The increase on population and extensive occupation of the Mediterranean region since 1980s contribute to the perception of increasing flood risk (CITE). However, it is also important to state that climate conditions with strong seasonal temperature variations is expected to favor cyclogenesis whenever inflows of cold air enter the Mediterranean, specially in autumn (Llasat and Puigcerver, 1994).

In the western coast of Italy, Corsica, and Sardinia flood producing mechanism are related with meridional circulation associated with Mediterranean depressions, northern troughs reaching the Mediterreanean, or depressions coming from northern Africa (Piervitali and Colacino, 2003). In the Tiber River (Central Italy) extreme events were particularly frequent at 1400-1500 and 1600-1700 (Camuffo *et al.*, 2003; see Figure 4-7). These two periods were characterised by an increased frequency of great and severe winters and under these circumstances the cyclogenesis was enhanced by a greater contrast between the seawater and the colder air masses (Camuffo *et al.*, 2003). The former was documentary described as a wet period, which included the Spörer Period of minimum solar activity (1416-1534). The periods 1000-1400, 1500-1600 and 1700 onwards show a very low flood frequency, which was further reduced after the works had been done in the 19th century. In Italy the Spörer Minimum was a period that had been particularly hit by extreme meteorological events and overflows (Camuffo and Enzi, 1994; 1995a,b; Brazdil *et al.*, 1999; Glaser *et al.*, 1999). Extreme floods exceeding the 16 m stage (<2600 m^3s^{-1}) at Ripetta landing (16545 km^2) were not constant in time: four flood above 18 m (<3400 m^3s^{-1}) took place in a period of only 80 years during the 1530-1606 (Calenda *et al.*, 2005) at the starting of the Little Ice Age, intriguingly a period of reported low flood frequency by Camuffo *et al.* (2003). Recent flooding is difficult to evaluate in the context of climate change due to river regulation structures, with the largest flooding exceeding 2000 m^3s^{-1}, occurring in 1937 (2750 m^3s^{-1}), 1937 (2750 m^3s^{-1}), 1923 (230 m^3s^{-1}), 1947 (2300 m^3s^{-1}), 1929 (2050 m^3s^{-1}), 1976 (2050 m^3s^{-1}). In the December 2008 flood (12.55 m ca. 1400 m^3s^{-1}), large economic impacts demonstrated an increased flood vulnerability of Rome region despite of decreasing flood hazard by flow regulation at basin scale (Natale and Savi, 2007). In the 20th Century, flood events exceeding 1400 m3s-1 prior to 1970s occurred at an average frequency of 7 times per decade, whereas after 1970s decreased to about 5 events.

Regarding droughts, it is more difficult to define distinct periods due to their complex spatial distribution, but in the Iberian Peninsula were clearly more frequent in the middle 16th (1540-1570) and 17th centuries (1625-1640), less severe in 1750-1760, as well as between 1810-1830 and 1880-1910 (Barriendos, 2002). The existence of periods with flood frequency together with droughts should also be mentioned. To date only one such period is known, between 1760 and 1800, but its effects spread throughout much of Western and Central Europe, with a clear impact on agricultural production and even social crises in different countries (Barriendos and Llasat, 2003).

4.3.4. Observed Trends in Human Systems and Sector Vulnerability to all Climatic Extremes and to Specific Types of Hazards

4.3.4.1. Vulnerability Trends

Section 3.3 shows that human exposure to climatic hazards is increasing. This is to some extent inevitable as population increases, as humanity expands activities in all regions and as resources are increasingly won from more difficult and expensive sources. However, the severity of the resulting impacts of climatic extremes depends on the vulnerability of what is exposed: on its susceptibility to harm and capacity for recovery. Much data on impacts conflate the effects of exposure with vulnerability as defined in this chapter.

Although all of humanity is exposed to some extent to climatic hazards and all have some vulnerability, there are some key factors in people's day to day existence that work at a very general level to undermine people's ability to manage their climate risks including their capacity to cope and recover from loss. Such factors include:

- War and chronic violence
- Being poor especially in rural areas due to livelihood insecurity
- Urban poor in informal settlements
- Living in a poor country or a small island country
- People without sound emergency support

- Areas with degraded ecosystems.

One indicator of trends in vulnerability may be provided by the impacts of climatic hazards (with appropriate normalisation of the data), although as these are impact data they may indicate more about the natural phenomenon and exposure rather than vulnerability. Care is needed in ascribing impact trends to vulnerability. Another approach is to examine trends in factors that increase or decrease vulnerability. These are generally factors of everyday life such as those set out in the paragraph above.

Higher levels of vulnerability may evolve from the sequence of natural and technological events and the interactions between them. For example, the initial disaster agent may be an invisible contaminant which affects the mental and physical health of those involved, with impacts persisting for years. Such impacts may undermine local resilience for subsequence events. A different sequence of events is that of a drought helping to create conditions ideal for wildfire, a high intensity wildfire resulting in ecological damage then exacerbated by a continuing drought that inhibits ecological and livelihood recovery, or heavy rain on the soil made bare by fire with serious erosion and similar losses.

4.3.4.2. Global and Regional Trends in Vulnerability Factors

Overall vulnerability appears to be fairly stable, although this general statement conceals a diverse range of trends including areas and groups where the trends are negative.

Dispossession by war or civil strife

Refugees and those driven into areas where livelihoods are marginal are often the most dramatic examples of people vulnerable to the negative affects of natural events, cut off from coping mechanisms and support networks. About half the world’s countries are directly linked to uprooted populations with people being forced to flee in some sixty countries (US Committee for Refugees 2000). Where warfare is involved, these areas are also characterized by an exodus of trained people and an absence of inward investment. Reasons for the increase in vulnerability associated with warfare include destruction or abandonment of infrastructure (transport, communications, health, education) and shelter, redirection of resources from social to military purposes, collapse of trade and commerce, abandonment of subsistence farmlands, lawlessness and disruption of social networks (Levy and Sidel 2000).

Poverty

The impacts of disaster are greatest on poorest households. Prevention’s *Global risk assessment* (2009) found that “Poor households are usually ..less resilient to loss and are rarely covered by insurance or social protection. Disaster impacts lead to income and consumption shortfalls and negatively affect welfare and human development, often over the long term.” Disaster impacts produce other poverty outcomes as well. Evidence from the 1984 drought and famine in Ethiopia shows that school enrolment tends to fall and children may grow at a slower rate due to nutritional shortfalls following disasters (Prevention, 2009). If people do not have enough to eat in normal times, they will be particularly badly impacted by extreme climatic events.

At the global level, it appears that poverty is decreasing. An important exception are the poorest billion people for whom income increased only slightly over the last decade. For the poorest ten percent the situation is much worse with a decrease in income (Nielsen, 2009). The number of those going hungry is increasing at about 4 million a year (FAO – SOFI, 2009) with a total of about 820 million. Over the last decade the proportion of people suffering from hunger in developing countries has gone down very slightly from 20 to 17 percent (FAO – SOFI, 2009).

Urban poor and informal settlements (from Prevention 2009)

Approximately one billion people worldwide live in informal settlements and the numbers are growing by approximately 25 million per year. Poor people in informal urban settlements typically have higher levels of everyday risk, even without considering the impact of natural hazards. For example, in Nairobi under-five mortality rates were 61.5 per 1,000 live births for the city as a whole in 2002, but approximately 150 per 1,000 in informal settlements. Evidence from cities in Africa, Asia and Latin America, shows that the expansion of informal settlements is closely associated with the rapid increase in weather-related disaster reports in urban areas. The comments on poverty and vulnerability above apply here as well.

Small island countries (from Prevention 2009)
"Countries with small and vulnerable economies, such as many small-island developing states ..(SIDS) and land-locked developing countries (LLDCs), have the highest economic vulnerability to natural hazards. Many also have extreme trade limitations."

Emergency support (from Prevention 2009)
"In general terms, countries are making ..significant progress in strengthening capacities, institutional systems and legislation to address deficiencies in disaster preparedness and response. Good progress is also being made in other areas, such as the enhancement of early warning. In contrast, countries report little progress in mainstreaming disaster risk reduction considerations into social, economic, urban, environmental and infrastructural planning and development."

Ecosystems
The Millennium Assessment found that the supply of approximately 60% of the ecosystem services evaluated (15 of 24) was in decline. However, consumption of almost all ecosystem services is increasing. Demand and service flow is increasing as the stock is decreasing. People have modified ecosystems to increase the supply of provisioning services, these same modifications have led to the decline of regulating ecosystem services, including those responsible for mitigating hazards, such as fires and floods (Millennium Ecosystem Assessment 2005).

4.3.4.3. Observed Trends in Human Systems and Sector Vulnerability to all Climatic Extremes and to Specific Types of Hazards

Water sector
The "water sector" includes:

- Provision of water supplies to customers (municipal, industrial, agricultural)
- Management of the flood hazard (coastal, river and pluvial)
- Management of water quality (for environmental and public health reasons)
- Management of freshwater ecosystems.

Changes in vulnerability to climate extremes in the water sector are driven by both changes in the volume, timing and quality of water (Section 4.3.3) and changes in the property, lives and systems using the water resource or exposed to water-related hazard. With a constant resource or physical hazard, there are two opposing drivers of change in vulnerability. On the one hand, vulnerability increases as more demands are placed on the resource (due to increased water consumption, for example, or increased discharge of polluting effluent) or more property, assets and lives are exposed to flooding. (*There are many published examples of trends on flood losses / water resource scarcity / pollutant loadings – perhaps tabulate some?*). On the other hand, vulnerability is reduced as measures are implemented to improve the management of resources and hazards, and to enhance the ability to recover from extreme events. For example, enhancing water supplies, improving effluent treatment and improved flood management measures (including the provision of insurance or disaster relief) would all lead to reductions in vulnerability in the water sector. The change in vulnerability in any place is a function of the relationship between these two opposing drivers, which also interact. Flood or water management measures may reduce vulnerability in the short term, but increased security may generate more development and ultimately lead to increased vulnerability.

The number of water-related disaster has increased at global scale for recent years (see Figure 4-8). The factors that have led to increased water-related disasters are thought to include natural pressures, such as climate variability; management pressures, such as the lack of appropriate organizational systems and inappropriate land management; and social pressures, such as an escalation of population and settlements in high-risk areas (particularly for poor people) (Adikari and Yoshitani, 2009). Contribution of factors to the increasing trend in water-related disasters is site-specific and cannot be concluded without detailed analysis. However, through the analysis of historical time-series data of disaster, trend in vulnerability to water-related hazards can be roughly understood.

[INSERT FIGURE 4-8 HERE:
Figure 4-8: Water-related disaster events recorded globally, 1980 to 2006 (Adikari and Yoshitani, 2009).]

Adikari and Yoshitani (2009) analyzed trends in water-related disasters based on CRED data for the period 1980 to 2006. Table 4-9 summarizes the recent trend of water-related disasters by hazard. Water-related disasters are clearly increasing every year and that future development is just as much at risk. However, the number of fatalities has decreased drastically, due to the efforts of those involved in the process of disaster management. As typical successful practice, we can exemplify the experience of Bangladesh where the numbers of fatalities due to similar magnitude cyclones decreased from more than 300000 in 1970 to just over 5000 people in 2007 (Adikari and Yoshitani, 2009), and the experience of Mozambique whose death tolls of serious floods in 2007 and 2008 were much smaller than that in 2000 (International Federation of Red Cross and Red Crescent Societies, 2009). Both cases can be linked to the progress in disaster management including effective early warning system. However, these good cases do not mean that early warning systems have evolved sufficiently to avoid massive casualties from natural hazards, as demonstrated by the 138,000 deaths in 2008 from Cyclone Nargis in Myanmar (International Federation of Red Cross and Red Crescent Societies, 2009).

[INSERT TABLE 4-9 HERE:
Table 4-9: Trend of water-related disasters from 1980 to 2006 by hazards (based on Adikari and Yoshitani, 2009).]

For thinking about historical change in vulnerability to droughts, it would be worth capturing trends of water withdrawal, demand side. With rapid population growth water withdrawals have tripled over the last 50 years. This trend is explained largely by the rapid increase in irrigation development stimulated by food demand in the 1970s and by the continued growth of agriculture-based economies. Emerging market economies (such as China, India and Turkey) still have an important rural population dependent on water supply for food production. They are also experiencing rapid growth in domestic and industrial demands linked to urbanization and related changes in lifestyle. There are hot spots in these countries where rural and urban demands are in competition (World Water Assessment Programme,2009).

Economy and transport

There is increasing vulnerability to weather/climate extremes partly because of the increasing value of assets exposed, but partly also because of increased interconnections between systems/sectors/places. The normal practice of just in time management and logistics is efficient financially but results in very little capacity in the event of a system breakdown as a result of an extreme event for example. Increasing volumes of traffic of all types increasingly takes systems to full capacity resulting in severe disruption to dependent sectors from for example a extreme weather event. Extreme events in one place can therefore have knock-on effects to other parts of the economy in other places.

Human Health

The largest research gap is a lack of information on impact outcomes in developing countries in general. This includes mortality/morbidity data and information on other contributing factors such as nutritional status or access to safe water and medical facilities. Only a limited number of places in developing countries have been investigated. The lack of information is inherent in developing countries, where public health infrastructure is poor and where the impact would be greatest due to both severe hazards and lower coping capacity. Within the developing countries, lower socio-economic status usually worsens vulnerability.

4.3.4.4. Case Study – Extraordinary Heat Wave in Europe, Summer 2003

An extraordinarily severe heat wave over large parts of the European continent occurred in the summer of 2003. It produced record-breaking temperatures particularly during June and August (Beniston, 2004; Schär *et al*., 2004). Absolute maximum temperatures exceeded the record highest temperatures observed in the 1940s and early 1950s in many locations in France, Germany, Switzerland, Spain, Italy and the UK. In many places of southern Europe, the peak temperatures exceeded 40°C.

Average summer (June to August) temperatures were by up to five standard deviations above the long-term mean, implying that this was an extremely unlikely event under current climatic conditions (Schär and Jendritzky, 2004). Gridded instrumental temperatures (from CRUTEM2v for the region 35°N–50°N, 0–20°E) show that the summer was the hottest since comparable records began in 1780: 3.8°C above the 1961 to 1990 average and 1.4°C hotter than any other summer in this period. Based on early documentary records, Luterbacher *et al.* (2004) estimated that 2003 is very likely to have been the hottest summer since at least 1500. As such, the 2003 heat wave resembles simulations by regional climate models of summer temperatures in the latter part of the 21st century under the A2 scenario (Beniston, 2004). Anthropogenic warming may therefore already have increased the risk of heatwaves such as the one experienced in 2003 (Stott *et al.*, 2004).

The heat wave od the summer of 2003 was accompanied by annual precipitation deficits in many parts of western and central Europe, up to 300 mm (Trenberth *et al.*, 2007). This led to considerable reduction of soil moisture and surface evaporation and evapotranspiration, and thus to a strong positive feedback effect (Beniston and Diaz, 2004). The drought contributed to the estimated 30% reduction in gross primary production of terrestrial ecosystems over Europe (Ciais *et al.*, 2005). This reduced agricultural production and increased production costs. The (uninsured) economic losses for the agriculture sector in the European Union were estimated at €13 billion, with largest losses in France (€4 billion) (Sénat, 2004). A record drop in crop yield of 36% occurred in Italy for maize grown in the Po valley, where extremely high temperatures prevailed (Ciais *et al.*, 2005). In France, compared to 2002, the maize grain crop was reduced by 30% and fruit harvests declined by 25%. The hot and dry conditions led to many very large wildfires. The extreme glacier melt in the Alps prevented even lower river flows in the Danube and Rhine (Fink *et al.*, 2004).

The 2003 heatwave *cum* drought in Europe affected settlements and economic services in a variety of ways, creating stress on health, water supplies, food storage and energy systems. Many major rivers (e.g., the Po, Rhine, Loire and Danube) were at record low levels, resulting in disruption of inland navigation, irrigation and power-plant cooling (Beniston and Díaz, 2004; Zebisch *et al.*, 2005). In France, electricity became scarce, construction productivity fell, and the cold storage systems of 25-30% of all food-related establishments were found to be inadequate (Létard *et al.*, 2004). The punctuality of the French railways fell to 77%, from 87% twelve months previously. Sales of clothing were 8.9% lower than usual in August, but sales of bottled water increased by 18%, and of ice cream by 14%. The tourist industry in Northern France benefited, but in the South it suffered (Létard *et al.*, 2004).

Impacts of the heatwave were mainly health- and health-service related; but they were also associated with settlement and social conditions, from inadequate climate conditioning in buildings to the fact that many of the dead were elderly people, left alone while their families were on vacation. Electricity demand increased with the high heat levels; but electricity production was undermined by the facts that the temperature of rivers rose, reducing the cooling efficiency of thermal power plants (conventional and nuclear) and that flows of rivers were diminished; six power plants were shut down completely (Létard *et al.*, 2004).

The excess deaths due to the extreme high temperatures during the period June to August, in Belgium, the Czech Republic, Germany, Italy, Portugal, Spain, Switzerland, the Netherlands and the UK, may amount to 35,000 (Kosatsky, 2005). Elderly people were among those most affected (WHO, 2003; Kovats and Ebi, 2006) – in France, around 60% of the heat wave deaths occurred in persons aged 75 and over (Hemon and Jougla, 2004). The heat wave in 2003 has led to the development of heat health-watch warning systems in several European countries – many governments (local and national) have implemented heat health-prevention plans , most of which are targeted towards a reduction of the short-term mortality (Michelozzi *et al.*, 2005; WHO Regional Office for Europe, 2006; Pascal, 2008).

In July 2006, France experienced the first major heat wave since the implementation of its heat prevention plan. Following the hypothesis that heat-related mortality had not changed since 2003, 6452 excess deaths were predicted from the observed temperatures, i.e. substantially less than observed 2065 excess deaths that actually occurred. The mortality lower than expected can be partially explained by a decrease in the population's vulnerability and by the efficiency of the prevention plan (Pascal, 2008).

4.3.4.5. Case Study – Glacial Retreat: Himalaya and Andes [move to Chapter 3?]

Glaciers in temperate and tropical latitudes are considered one of the best indicators of climate change, due to their sensitivity to climatic variations and public perception of temperature change in mountain regions (IPCC in McCarthy *et al*., 2001; Haeberli, 2006). In general terms, valley glacier fluctuations have followed a similar pattern to temperature change, with strong glacier retreats in the 1940s, stable or growing conditions around the 1970s, and again increasing rates of ice loss since the mid 1980s (WGMS, 2008; see Figure 4-9). Small glaciers have retreated at faster rates than large glaciers due to a lag time in response of the latter; similarly, low latitude and/or low elevation mountain glaciers shrink faster than high latitude and/or high elevation glaciers (WGMS, 2008). In the Himalayas, the average rate of glacier retreat is ca 10 m per year, although in extreme cases, such as Imja glacier, it has increased from 59 m per year (1962-2001) to 74 m over the period 2001-2006 (Bajracharya, 2007). A direct effect of glacier dynamic is the formation and disappearance of ice- and moraine-dammed lakes. Moraine-dams may experience degradation through melting of ice cores (Richardson and Reynolds, 2000), erosion and seepage (O'Connor *et al*., 2001), and their glacial lakes may increase in volume from accelerated glacier melting (Clague and Evans, 2000). Existing glacier-dammed lakes may also drain catastrophically through ice-marginal drainage, mechanical failure of part of the ice dam or by a tunnel incised into the basal ice or a combination of both (Walder and Costa, 1996).

[INSERT FIGURE 4-9 HERE:
Figure 4-9: Anomalies in northern hemisphere snow cover since 1965 (UNEP GRID, ____).]

Glacial outburst floods are highly threatening because they occur suddenly with little or no warning, and therefore floods are unexpected for riverine communities, and can be much larger than usual rain or snowmelt floods. Common flood discharges from historically breached moraine dams range between 200-4000 m^3s^{-1}, but at least on two outburst floods a peak was recorded of 10,000 m^3s^{-1} for a drained volume in excess of 18 million m^3 of water (e.g. Tam Pokhari Glacier Lake in Nepal after a 60 m-height dam collapse, Dwivedi *et al*., 2000). Ice-dammed lake failures have produced a larger peak discharge than moraine lakes containing similar water volume, with the largest one reaching 112,500 m^3s^{-1} (October 1986 GLOF from Russell Fjord; Mayo, 1989), about three times the largest Mississippi flood. Outburst from small subglacial, supraglacial and englacial water bodies also may cause flood hazards for down valley human activities.

Areas susceptible to outburst floods are inherent to the presence of large proglacial lakes including the Himalayas (Yamada, 1998; Mool *et al*., 2001; Richardson and Reynolds, 2000), the Andes (Ames *et al*., 1989; Kaser and Osmaston, 2002; Dussaillant *et al*., 2009), the Alps (Lliboutry *et al*., 1977, Haeberli *et al*., 2001; Huggel *et al*., 2004; Kaab *et al*., 2005), central Caucasus (Petrakov *et al*., 2007), and the Cordillera of western North America (Clague and Evans, 2000; O'Connor *et al*., 2001). An inventory of glacial lakes in Himalayas shows a potential high risks on 24 of 2,674 glacial lakes in Bhutan, 20 of 2,323 glacial lakes in Nepal, 16 of 156 glacial lakes in India (data from three states: Himachal Pradesh, Uttarakhand and Sikkim), and 52 of 2,420 glacial lakes in Pakistan (ICIMOD in Bajracharya *et al*., 2007). During the 1934-1998 period, the frequency of glacial-lake outburst floods in the Himalayas of Nepal, Bhutan and Tibet has increased from 0.38 events/year in 1950s to 0.54 events/year in 1990s (Richardson and Reynolds, 2000 in Rosenzweig *et al*., 2007). In the Andes region, although still largely unknown, vulnerable sites amount to over a dozen glacial and moraine lakes in Chile (Peña and Escobar, 1983; Harrison *et al*., 2006), and in Cordillera Blanca (Peru) as ca 600 glaciers have retreated ~25% over the last 30 years, with an increase on number of glacial lakes from 223 in 1953 to 374 in 1997, among which precarious dam conditions were identified in at least 35 glacial lakes (Carey, 2005). In the Northern Patagonia Ice Field, the rapid succession of five outburst floods from ice-dammed lake Cachet 2 (230 million m^3) during 2008-2009 caused considerable damage to local settlements along the Baker River, after more than 40 years without any outburst flood event (Dussaillant *et al*., 2009).

Glacier retreat is increasing the number and size of glacial lakes, requiring an extra effort for inventory and monitoring of existing and new developed lakes. The highest GLOF hazard is usually related to glacial lakes dammed by young, unstable and unconsolidated moraines, and lakes in contact to the active ice body of a glacier (Damen, 1992). Processes involved in the formation and disappearance of glacial lakes are very dynamic in the current warming conditions (Quincey *et al.*, 2007), and new emerging lakes may cause a catastrophic disaster in areas not considered to be GLOF-prone, and vice-versa (Osti and Egashira, 2009). In fact, it is not unusual that local population learn about the very existence of a glacial lake after it has produced a GLOF event (Petrakov *et al.*, 2007). Remote sensing techniques, namely SAR interferometry, LIDAR and satellite images (Landsat, Spot and IRS), are being used to identify and monitor glacial lake changes (Huggel *et al.*, 2004; WGMS, 2008), and as a predictive tool for identifying those glaciers with an expected tendency towards lake formation over a time-scale of the order of a few decades (Quincey *et al.*, 207). The most unstable glacial lakes require real time monitoring of both lake and glacier, together with updated hazard maps and mitigation measures, mainly at the source, via lake monitoring and controlled drainage (Grabs and Hanish, 1993). Other elements requiring monitoring include dam failure triggering events (e.g. large ice mass from glacier tongue resulting in surge waves and lake overflow), and dam stability (e.g. seepage and piping resulting in local dam failure: Grabs and Hanish, 1993; Haeberli *et al.*, 2001), and seismic activity, particularly on those areas with active volcanism (e.g. Iceland *et al.*, 2003).

Human activities affected by glacial hazards include settlements, hydropower production, forestry, mining and wilderness tourism (Clague and Evans, 2000; Richardson and Reynolds, 2000). Rapid socio-economic growth of mountain regions increases the GLOF risk potential, and actions are needed to identify and monitor hazard sources, identify downstream vulnerable zones, reduce and mitigate GLOF risk, prevent life losses and minimize economic losses (Table 4-10). New economic activities introduced on mountain regions, such as hydropower plant developments, may underestimate GLOF risks. A small hydropower plant in Nepal was destroyed by an outburst flood from the Dig Tsho Lake, in August 1985 (Vuichard and Zimmermann, 1987). This is particularly relevant in view of the planned development of large hydropower projects in the Baker River in Chilean Patagonia, now questioned after the five self-forming outburst floods from Cachet 2 Lake (Dussaillant *et al.*, 2009). Effective risk management should address the changing vulnerability and new patterns of glacial-related hazards with severe socio-economic consequences (Rosenzweig *et al.*, 2007). Adaptation measures are limited and in most cases requires a relocation of human settlements and new risk assessment for planned infrastructure (hydropower, bridges, etc.) in the view of potential outburst floods (Adger *et al.*, 2007).

[INSERT TABLE 4-10 HERE:
Table 4-10: Risk, glacier outburst floods, and management.]

4.3.5. Observed Trends in Ecosystem Vulnerability to all Climatic Extremes and to Specific Types of Hazards (e.g., drier, hotter, conditions can lead to very high intensity fires)

Extreme climatic events have increased in frequency and magnitude, but their ecological impacts are far away from fully understood. Climatic extremes (drought, heat wave, flood, frost, ice, and storm) and specific hazards were observed to have widespread effects on ecosystems, including physiology, development, biodiversity, phenology and carbon balance.

4.3.5.1. Drought and Heat Wave

The effects of drought and heat wave were widespread. A higher sensitivity to drought was found in the beech, and surprisingly, in the broadleaved Mediterranean forests; the coniferous stands (spruce and pine) appeared to be less drought-sensitive (Granier, Reichstein et al. 2007). The effects of drought accompanied by extreme warm temperature mainly include growth decline, species death or mortality, spatial shift and carbon balance.

4.3.5.1.1. Growth decline

The aboveground net primary productivity declined at a short grass steppe site in Colorado, USA at the two years of extreme drought (1954 and 1964) (Lauenroth *et al.*, 1992). A crown condition declined following severe droughts for beech such as drought in 1976 (Power, 1994), 1989 (Innes, 1992) and 1990 (Stribley *et al.*, 2002)). The percentage of moderately or severely damaged trees displayed an upward trend after the 1989's drought in Central

Italy, especially for *Pinus pinea* and *F. sylvatica* (Bussotti *et al.*, 1995). Defoliation and mortality in Scots pine observed in each year during 1996–2002 was related to the precipitation deficit and hot conditions of the previous year in the largest inner-alpine valley of Switzerland (Valais) (Rebetez *et al.*, 2004). Both gross primary production and total ecosystem respiration decreased in 2003 in many regions of Europe (Granier, Reichstein et al. 2007).

The time-lag between climatic extremes and forest decline is widespread, which may enhance vulnerability to more frequent climate extremes. Five years after the exceptional 2003 summer, forest declines are mentioned in many forests all over Europe. The unusual heat and drought in summer 2003 caused a severe reduction in water availability and transpiration of several forests stands in Central Europe. This led to leaf loss increase on these plots for many species as soon as 2004 and the following years (Bréda *et al.*, 2008). The growth reduction in beech was more pronounced in the year following the drought (2004) (Granier, Reichstein et al. 2007). Although precipitation recovered to near normal levels in the ensuing years after extreme drought, the aboveground net primary productivity showed a lag in recovery of 1–3 years, which they attribute to changes in vegetative structure (Lauenroth *et al.*, 1992).

4.3.5.1.2. Species death or mortality

The death of species was the ultimate stage triggered by extreme drought that acts as a bottleneck event affecting changes in co-occurring species. Abnormal mortality was observed either soon after the climatic event (autumn 2003), or at the beginning of 2004 when spring budburst did not arise for a lot of trees. A mortality rate of 1.3% for coniferous trees was observed in French, representing a spectacular increase in comparison with the average normal level of 0.2%. At the European scale, tree mortality varied from 0.8 to 1.2%, with a continuous increase up to 2006 after recurrent droughts, especially for broad-leaved species. The exceptional increase of coniferous species mortality in 2004 was the result of earlier, stronger and longer soil water deficit, direct impact of heat wave on crowns (Bréda *et al.*, 2008).

A rapid, drought-induced die-off of overstory woody plants at sub-continental scale was triggered by the recent drought (2000-2003) in southwestern North America. After 15 months of depleted soil water content, >90% of the dominant, overstory tree species (*Pinus edulis*, a piñon) died. The limited, available observations suggest that die-off from the recent drought was more extensive than that from the previous drought of the 1950s, extending into wetter sites within the tree species' distribution (Breshears *et al.*, 2005). Regional-scale pinon pine mortality was following an extended drought (2000–2004) in northern New Mexico (Rich *et al.*, 2008). Dominant species from diverse habitat types (i.e., riparian, chaparral, and low-to-high-elevation forests) exhibited significant mortality during a drought in the southwestern United States; and average mortality differed among dominant species was 3.3%-41.4% (Gitlin *et al.*, 2006).

4.3.5.1.3. Spatial shift

A rapid shift of a forest ecotone was caused by *Pinus ponderosa* mortality in response to the 1950s drought (Allen et al., 2005). The severe drought in 2004–2005 was responsible for spatial shifts in the estuary regarding zooplankton community and inter-annual variability, with an increase in abundance and diversity during the period of low freshwater flow in a shallow temperate southern European estuary, the Mondego Estuary Portugal. The occurrence of such estuarine community contributed to the increase in zooplankton abundance which is ascribed to the estuarine species *Acartia tonsa*. (Marques *et al.*, 2007).

4.3.5.1.4. Carbon balance

More frequent anomalously warm years may lead to a sustained decrease in carbon dioxide uptake by terrestrial ecosystems. The extreme conditions pushed many forest ecosystems from being a net C sink to being a net C source. Net ecosystem carbon dioxide exchange decreased in both the extreme warming year (2003) and the following year in tall-grass prairie in central Oklahoma, USA (Arnone *et al.*, 2008). A 30% reduction in gross primary productivity together with decreased ecosystem respiration over Europe during the heatwave in 2003, which resulted in a strong anomalous net source of carbon dioxide (0.5 Pg Cyr(-1)) to the atmosphere and reversed the effect of four years of net ecosystem carbon sequestration. Such a reduction in Europe's primary productivity is unprecedented during the last century (Ciais *et al.*, 2005). As for grassland ecosystems, the significant decrease in the efflux of CO_2, which was equal to about 1/5 of that during the corresponding period of 1998, resulted from extreme drought in Inner Mongolia, China in 2001 (Li *et al.*, 2004).

4.3.5.2. Flood

An extreme flood event was punctuational perturbations that caused large, rapid population- and community-level changes that were superimposed on a background of more gradual trends driven by climate and vegetation change (Thibault *et al.*, 2008).

An extreme flood event affected a desert rodent community near Portal, AZ since 1977 by causing catastrophic, species-specific mortality and resulting in rapid, wholesale reorganization of the community (Thibault *et al.*, 2008). Floods were observed to directly impact on Huelva, by wiping out part of its population in the Mondego estuary, located on the Atlantic coast of Portugal. Over the period when the estuary experienced eutrophication, extreme weather events contributed to the overall degradation of the estuary, while during the recovery phase following the introduction of a management programme, those extreme weather episodes delayed the recovery process significantly (Cardoso *et al.*, 2008).

4.3.5.3. Storm

Winter storms are considered key climate risks, particularly in prealpine and alpine areas (Fuhrer *et al.*, 2006). Since 1868 European forests were impacted at least 16 times by the effects of several severe storms (Schelhaas *et al.*, 2003), and 10 times since the early 1950s with windthrow of over 20 million m3; damages in 1990 and 1999 were by far the worst of all these years (UN/ECE Timber Committee, 2000). A damaging ice storm struck northern New England, NY, and adjacent Canada in 1998, affecting nearly 7 million ha of forest lands (Faccio, 2003).

4.3.5.4. ENSO

The El Niño-Southern Oscillation (ENSO) events have strong ecological consequences, especially changes in marine ecosystems. Particularly striking were widespread massive coral bleaching events that followed the 1982-1983 (Glynn, 1988) and 1997-1998 (Wilkinson, 1999) El Niño events. There has been significant bleaching of hard and soft corals in widely separate parts of the world from mid-1997 to the last months of 1998. Much of this bleaching coincided with a large El Nino event, immediately switching over to a strong La Nina. Some of the reports by experienced observers are of unprecedented bleaching in places as widespread as (from west to east) the Middle East, East Africa, the Indian Ocean, South, Southeast and East Asia, far West and far East Pacific, the Caribbean and Atlantic Ocean. Catastrophic bleaching with massive mortality was reported, often near 95% of shallow (and sometimes deep water) corals such as in Bahrain, Maldives, Sri Lanka, Singapore, and parts of Tanzania (Wilkinson, 1999).

By contrast, the effects of ENSO events on terrestrial ecosystems have been seldom investigated. ENSO-induced pulses of enhanced plant productivity can induce the spectacular greening and flowering of deserts (Dillon *et al.*, 1990), and can cause open dry-land ecosystems to shift to permanent woodlands (Holmgren *et al.*, 2001).

No information does not means that no problems of adverse impacts of extreme events and disasters on ecosystems in developing societies. (Because of lack of researches or maybe lack of only references in English, there are fewer literatures on climate extreme impacts of climate change and disasters on ecosystems. It is likely that the researches in developing countries were published in other languages than English. For example, the on-going second National

Assessment Report on Climate Change in China would include such information of China. The report have not yet been allowed to cite or reference)

4.3.5.5. Case Study – Coral Reef Bleaching

Coral reefs are common features in tropical and subtropical coasts, providing ecosystem service that includes food production, tourism and recreation, and disturbance regulation (coastal protection). The economic value of the world's coral reefs was estimated to be 29,830 million US$ and 797,530 million US$ for net benefit per year and net present value over a 50-year timeframe, respectively (Cesar, 2003). Coral reefs, however, suffer rapid degradation (Hoegh-Guldberg *et al.*, 2007). Recent estimate shows that 20% have been destroyed, and 50% are threatened (Wilkinson, 2004). One-third of coral species face elevated extinction risk (Carpenter *et al.*, 2008).

One of the major causes is coral reef bleaching, due to the loss of symbiotic algae, which has most commonly been associated with anomalously high sea surface temperatures (SSTs), typically with 1.0-1.5 ˚C above seasonal maximum mean SSTs (e.g., Baker *et al.*, 2008). The number of bleaching events observed is increasing (see Figure 4-10), possibly in response to SST rise due to global warming. Retrospective analysis of SSTs and bleaching occurrences indicated that bleaching was correlated well with anomalously high SST (e.g., Berkelmans *et al.*, 2004; McWilliams *et al.*, 2005).

[INSERT FIGURE 4-10 HERE:
Figure 4-10: Coral bleaching record.]

Of all the years, the 1998 bleaching was unprecedented and most devastating in its geographical extent and severity. It was caused by anomalously high SST because of pronounced El Nino events in one of the hottest year on record (Lough, 2000). This event caused mass mortality of corals and damaged coral reefs' ecosystem service not only in food production and tourism and recreation but also in disturbance regulation. For example, in Seychelles of the Indian Ocean, the function of coastal protection due to coral reefs was partially lost due to coral mortality (Sheppard *et al.*, 2005). Overall, the total economic damage estimated over a 20-year timeframe was calculated to be maximum 8,190 million US$ for the Indian Ocean (Wilkinson *et al.*, 1999).

The rising SST could cause higher bleaching intensity in the future. Results from atmosphere-ocean general circulation models (GCMs) from the third assessment of IPCC indicated that bleaching could become an annual or biannual event for the vast majority of the world's coral reefs in the next 30-50 years (Donner *et al.*, 2005). Using more recent GCMs, Donner *et al.* (2007) and Yara *et al.* (2009) showed similar trends in the eastern Caribbean and northwestern Pacific, respectively. As evidenced in 1998, pronounced El Nino events caused by climate change would make bleaching more severe.

Though anomalously high SSTs have been accepted as the major cause of widespread bleaching, refining the prediction and consequences may be required, because bleaching and the resulting coral mortality can be a result of interaction of various environmental variables (including SST) and acclimatization of corals. Bleaching could be caused by other stressors, including ocean acidification (Anthony *et al.*, 2008), high solar radiation, freshwater discharge and sedimentation, all of which are related to climate change and human activities. On the other hand, bleaching may be mitigated by strong water motion (Nakamura *et al.*, 2005), sometimes caused by typhoons (Manzello *et al.*, 2007), which are also related to climate change. Further, adaptation and acclimatization of corals to high SST could happen (Baker *et al.*, 2008). These recent advances in knowledge of coral bleaching may require considering multiple variables to estimate susceptibility of current and future coral reefs (e.g., Donner *et al.*, 2005, 2007; McClanahan *et al.*, 2007; Maina *et al.*, 2008).

4.3.6. Issues of Sequencing and Frequency of Climatic Extremes (e.g., ratcheting effect) [on impacts]. The impact of multiple hazards each one of which is not necessarily an "extreme".

[*Placeholder Only*] The sequence or order of climatic extremes can have a major affect in a number of ways. The sequence can undermine resilience where an event makes people or ecosystems more vulnerable or more exposed to another extreme. This can happen through damage to livelihoods or to areas that protect settlements or otherwise vulnerable ecosystems. Sequences need not necessarily all be "extreme events". Frequent relatively small events can alter ecosystems and impair livelihoods in ways that are not noticed by external observers.

4.3.7. Comment on 4°C Rise

To be completed.

4.4. System- and Sector-Based Aspects of Vulnerability, Exposures, and Impacts

4.4.1. Criteria Used for the Tables in this Section

The information is set out in Table 4-11. This table considers systems and sectors by exposure, vulnerability and impacts. Systems are human and natural (ecosystems). Sectors considered are: food, health, water, ecosystem, forestry, tourism, economy, infrastructure/settlements, energy and other. Exposure and vulnerability are as defined earlier in this chapter with vulnerability being susceptibility to harm and capacity to recover. Exposure is being in the way of the climatic extreme. All climatic extremes covered in Chapter 3 plus wildfires and erosion.

[INSERT TABLE 4-11 HERE:
Table 4-11: Links between sectors, exposure, vulnerability, and impacts.]

Data on impacts are generally available at various levels of aggregation. But these often do not allow the issues of the severity of the natural phenomenon, exposure and vulnerability to be examined separately. Without either this capacity or careful normalization of the data to isolate the factors we are interested in, the results do not tell us much about the issues we want to examine.

4.4.2. The Overall Links between Systems, Sectors, and Hazard Impacts (including vulnerability and exposure)

In this sub-section, according to the criteria discussed in 4.1, existing studies which assessed impacts and risks of extreme events or extreme impacts are surveyed for each major affected sectors/system. Generally, there is limited literature on the potential future impacts of extreme events, while most literature is subject to work on analyzing current risks of extreme events based on observed states and trends of factors. It might be partially due to the limited availability of reliable detailed knowledge on change in extreme events as well as other various factors related to vulnerabilities in future. However, if factors constituting current risks are understood and sorted out, stakeholders including policymakers could make use of the knowledge for thinking of future risks roughly and preparing for them with various kinds of policy and measures. Therefore analyses of observed impacts due to extreme events as well as of projected future risks are taken up. Below, coverage of knowledge on current/future risks of extreme events is evaluated and findings of major researches are introduced by sectors/systems.

4.4.2.1. Water

This section assesses evidence for future changes in extreme aspects of freshwater resources, focusing on water supply and floods (coastal floods are covered in Section 4.4.2.4). The evidence is assessed at the "local" scale (the scale at which water supplies and floods are managed), the national scale and the international scale.

In terms of water supply, an extreme event is one which challenges the ability of the water supply "system" (from highly-managed systems with multiple sources to a single rural well) to supply water to users. This may be because a surplus of water affects the operation of systems, but more typically results from a shortage of water relative to demands – a drought. Water supply shortages may be triggered by a shortage of river flows and groundwater, a deterioration in water quality, an increase in demand, or an increase in vulnerability to water shortage. Reductions in river flows or groundwater recharge may be a result of climate change (see Chapter 3), of changes in catchment land cover, or changes in upstream interventions. A deterioration in water quality may be driven by climate change (Chapter 3), change in land cover or upstream human interventions. An increase in demand may be driven by demographic, economic, technological or cultural drivers (Chapter 2). An increase in vulnerability to water shortage may be caused by, for example, increasing reliance on specific sources or volumes of supply, or changes in the availability of alternatives (Chapter 2). Indicators of hydrological and water resources drought impact include lost production (of irrigated crops, industrial products and energy), the cost of alternative or replacement water sources, and altered human well-being, alongside consequences for freshwater ecosystems (impacts of meteorological and agricultural droughts on production of rain-fed crops are summarised in Section 4.4.2.3).

Although there have been many studies simulating potential effects of climate change on various hydrological indicators of drought at the local scale (see Chapter 3), very few studies have so far been published into the effect of climate change on the impacts of drought. Virtually all of these have looked at water system supply reliability during a drought, rather than indicators such as lost production, cost or well-being. Changes in reliability of course vary with local hydrological and water management circumstances, the details of the climate scenarios used, and the influence of changes in other drivers on drought risk. Some studies show large potential reductions in supply reliability due to climate change that challenge existing water management systems (e.g. Fowler et al., 2003, Vanham et al., 2009), some show relatively small reductions that can be managed – albeit at increased cost – by existing systems (e.g. Fowler et al., 2007), and some show that under some scenarios the reliability of supply *increases* (e.g. Kim and Kalvarachi, 2009; Li et al. 2010). Climate change is in many instances only one of the drivers of change in supply reliability, and is not necessarily the most important local driver. Macdonald et al. (2009), for example, demonstrate that the future reliability of small-scale rural water sources in Africa is largely determined by local demands, biological aspects of water quality or access constraints, rather than changes in regional recharge - because domestic supply requires only 3-10 mm of recharge per year. However, they noted that up to 90 million people in low rainfall areas (200-500mm) would be at risk if rainfall reduces to the point at which groundwater resources become non-renewable.

A number of countries have published national-scale assessments of the consequences of climate change and other drivers on the impacts of hydrological or water resources drought (e.g. Spain: Iglesias et al., 2005). There have been several continental or global scale assessments of potential change in hydrometeorological drought indicators (see Chapter 3), but only one published study of potential changes in an indicator of water resources drought *impact*. Lehner et al. (2006) calculated a drought deficit volume indicator across Europe, based on simulated river flows with consumptive abstractions (for municipal, industrial and agricultural uses) removed. They showed very substantial changes in the future return period of the present 100-year water resources drought deficit volume (see Figure 4-11a) with two climate scenarios: across large parts of Europe, the present 100-year drought deficit volume would have a return period of less than 10 years by the 2070s. Lehner et al. (2006) also demonstrated that this pattern of change was generally driven by changes in climate, rather than the projected changes in withdrawals of water (see Figure 4-11b). In southern and western Europe, changing withdrawals alone only increases deficit volumes by less than 5%, whereas the combine effect of changing withdrawals and climate change increases deficit volumes by at least 10%, and frequently over 25%. In eastern Europe, increasing withdrawals increase drought deficit volumes by over 5%, and more than 10% across large areas, but this is offset under both climate scenarios by increasing runoff.

[INSERT FIGURE 4-11 HERE:
Figure 4-11: Change in indicators of water resources drought across Europe by the 2070s (Lehner et al., 2006). a (top): change in the return period of the current 100-year drought deficit volume, with change in river flows and withdrawals, under two climate scenarios. b (bottom): change in the intensity (deficit volume) of the 100-year drought with changing withdrawals, with climate change (left, with the HadCM3 scenario) and without climate change (right).]

In terms of fluvial (river-based) floods, an extreme event is one which causes loss, damage or inconvenience to those living or working in flood-prone areas, and the wider community. An event may be extreme in terms of its frequency, timing (during the year) or duration. Climate change has the potential to change flood characteristics through changing the volume and timing of precipitation, and by altering the partitioning of precipitation between snow and rain (Chapter 3). However, changes in catchment surface characteristics – such as land cover – and the river network can also lead to changes in the physical characteristics of river floods. The impacts of extreme flood events include direct effects on livelihoods, property, health, production and communication, together with indirect effects of these consequences through the wider economy. The magnitude of these impacts depends on what is exposed to the flood hazard, how sensitive this exposure is to loss or damage, and the ability to recover or react to flood events. Future changes in the impacts of flooding will therefore be influenced not only by changes in climate, but also by changes in catchment and river properties and, significantly, changes in exposure and sensitivity to flood loss.

There have been a large number of studies into potential changes in the flood frequency curve due to climate change (e.g. Cameron (2006), Lehner et al. (2006), Hirabayashi et al. (2008), Dankers and Feyen (2008; 2009), Kay et al. (2009): see Chapter 3). These studies have concluded that the estimated effects of climate change are highly dependent on the climate models used to define scenarios and, to a lesser extent, the methodologies used to link climate model information with hydrological models. Under some scenarios changes may be small – or the frequency of flooding may reduce – but under others there may be a substantial change in the frequency with which specific extreme events are exceeded. For example, Dankers and Feyen (2008) showed, under one scenario, that in parts of Europe the current 100-year event would be exceeded more frequently than once every 50 years. As with droughts, however, few studies have translated changes in flood *frequency* into changes in flood *impact*.

An early study in the US (Choi and Fisher, 2003) constructed regression relationships between annual flood loss and socio-economic and climate drivers, concluding that a 1% increase in average annual precipitation would, other things being equal, lead to an increase in annual national flood loss of around 6.5%. However, the conclusions are highly dependent on the regression methodology used, and the spatial scale of analysis. More sophisticated analyses combine estimates of current and future damage potential (as represented by a damage-magnitude relationship) with estimates of current and future flood frequency curves to estimate event damages and average annual damages (sometimes termed expected annual damage). For example, Mokrech et al. (2008) estimated damages under the current 10-year and 75-year events in two regions of England. Their published results combine fluvial and coastal flooding, but it is possible to draw two main conclusions from their work. First, the percentage change in cost was greater for the rarer event than the more frequent event. Second, the absolute value of impact, and therefore the percentage change from current impact, was found to be highly dependent on the assumed socio-economic change; in one region, event damage under one socio-economic scenario was, in monetary terms, between 4 and 5 times the event damage under another scenario. An even wider range in estimated *average annual* damage was found in the UK Foresight Future Flooding and Coastal Defence project (Hall et al., 2005; Evans et al., 2004) which calculated average annual damage in 2080 of £1.5 billion, £5 billion and £21 billion under similar climate scenarios but different socio-economic futures (current average annual damage was estimated at £1 billion). The Foresight project represented the effect of climate change on flood frequency by altering the shape of the flood frequency curve using expert judgement based on changes in precipitation as simulated using a number of climate models. The EU-funded PESETA project (Ciscar, 2008; Feyen et al., 2009) used a hydrological model to simulate river flows, flooded areas and flood frequency curves, from climate scenarios derived from regional climate models, but – in contrast to the UK Foresight project – assumed no change in economic development in flood-prone areas. Table 4-12 summarises estimated changes in the numbers of people affected by flooding (i.e. living in flood-prone areas) and average annual damage, by European region (Ciscar, 2008). There are strong regional variations in impact, with particularly large increases (over 200%) in central and eastern Europe; in parts of north eastern Europe, average annual flood damages decrease.

[INSERT TABLE 4-12 HERE
Table 4-12: Impact of climate change by 2071-2100 on flood risk in Europe (Ciscar, 2008). Note that the numbers assume no change in population or development in flood-prone areas.]

At the global scale, Kleinen and Petschel-Held (2007) estimated the numbers of people affected by increased flood risk with different rates of increase of global temperature. Their indicator of impact is the percentage of population living in river basins where the return period of the current 50-year return period event is reduced to return periods between 40 years (the 50-year flood is 1.25 times as frequent) and 10 years (the 50-year flood is 5 times as frequent). They used three climate models to define changes in climate. With an increase in global mean temperature of 2ºC (above late 20th century temperatures), between (approximately) 5 and 28% of the world's population would live in river basins where the current 50-year return period flood occurs at least twice as frequently.

4.4.2.2. Ecosystems

According to IPCC AR4 (see IPCC AR4 WG2, 4.4) the most sensitive ecosystems to extreme climate include desert, grassland and Savanna, Mediterranean ecosystem, forest and woodland, tundra and Arctic/Antarctic ecosystems, mountains, forest and woodland, fresh water wetland, lakes and river, oceans and shallow seas, due to extreme warm, drought, fire, pets and ENSO etc.

Desert biodiversity is likely to be vulnerable to climate change (Reid et al., 2005), with winter-rainfall desert vegetation and plant and animal species especially vulnerable to drier and warmer conditions (Lenihan et al., 2003; Simmons et al., 2004; Musil et al., 2005; Malcolm et al., 2006). In the Succulent Karoo biome of South Africa, 2,800 plant species face potential extinction as bioclimatically suitable habitat is reduced by 80% with a global warming of 1.5-2.7ºC above pre-industrial levels. Daytime in situ warming experiments suggest high vulnerability of endemic succulent (see Glossary) growth forms of the Succulent Karoo to high-end warming scenarios for 2100 (mean 5.5°C above current ambient temperatures), inducing appreciable mortality in some (but not all) succulent species tested within only a few months (Musil et al., 2005). [see also IPCC AR4 WG2, 4.4.2]

Ecosystem function and species composition of grasslands and savanna are likely to respond mainly to precipitation change and warming in temperate systems but, in tropical systems, CO2-fertilization and emergent responses of herbivory and fire regime will also exert strong control. Sahelian woody plants, for example, have shown drought-induced mass mortality and subsequent regeneration during wetter periods (Hiernaux and Turner, 2002). Climate change is likely to increase fire frequency and fire extent. Greater fire frequencies are noted in Mediterranean Basin regions (Pausas and Abdel Malak, 2004) with some exceptions (Mouillot et al., 2003). [see also IPCC AR4 WG2, 4.4.3]

Soil water content controls ecosystem water and CO2 flux in the Mediterranean Basin system (Rambal et al., 2003), and reductions are very likely to reduce ecosystem carbon and water flux (Reichstein et al., 2002). [see also IPCC AR4 WG2, 4.4.4]

Since the TAR, most DGVM models based on A2 emissions scenarios show significant forest dieback towards the end of this century and beyond in tropical, boreal and mountain areas, with a concomitant loss of key services. Species-based approaches suggest losses of diversity, in particular in tropical forest diversity hotspots (e.g., north-eastern Amazonia – Miles, 2002) and tropical Africa (Mc Clean et al., 2005). Climate change impacts on forests will result not only through changes in mean climate, but also through changes in seasonal and diurnal rainfall and temperature patterns (as influenced by the hydrologically relevant surroundings of a forest stand, e.g., Zierl and Bugmann, 2005). If climate warms and this ecotone becomes exposed to more droughts, insect outbreaks will become a major factor (Logan et al., 2003; Gan, 2004). Climate changes including El Niño events alter fire regimes in fire-prone regions such as Australia (Hughes, 2003;Williams et al., 2004b;Allen Consulting Group, 2005), the Mediterranean region (e.g., Mouillot et al., 2002; see also Section 4.4.4), Indonesia and Alaska (Hess et al., 2001), but also introduce fire into regions where it was previously absent (e.g., Schumacher et al., 2006). [see also IPCC AR4 WG2, 4.4.5]

Disturbances such as avalanches, rockfall, fire, wind and herbivore damage interact and are strongly dependent on climate (e.g., Peñuelas and Boada, 2003;Whitlock et al., 2003; Beniston and Stephenson, 2004; Cairns and Moen, 2004; Carroll et al., 2004; Hodar and Zamora, 2004; Kajimoto et al., 2004; Pierce et al., 2004; Schoennagel et al., 2004; Schumacher et al., 2004). [see also IPCC AR4 WG2, 4.4.7]

Current extreme climatic events provide an indication of potential future effects. For example, the warm-water phase of ENSO is associated with large-scale changes in plankton abundance and associated impacts on food webs (Hays et al., 2005), and changes to behaviour (Lusseau et al., 2004), sex ratio (Vergani et al., 2004) and feeding and diet (Piatkowski et al., 2002) of marine mammals. [see also IPCC AR4 WG2, 4.4.9]

Ecological surprises include rapid and abrupt changes in temperature and precipitation, leading to an increase in extreme events such as floods, fires and landslides, increases in eutrophication, invasion by alien species, or rapid and sudden increases in disease (Carpenter et al., 2005). This could also entail sudden shifts of ecosystems to less desired states (Scheffer et al., 2001; Folke et al., 2004; e.g., Chapin et al., 2004) through, for example, the exeedance of critical temperature thresholds, possibly resulting in the irreversible loss of ecosystem services, which were dependent on the previous state (Reid et al., 2005). [see also IPCC AR4 WG2, 4.4.10]

4.4.2.3. Food systems and food security

Changes in temperature and precipitation patterns will affect food production systems. High temperatures stresses can manifest themselves in different ways during the growth cycle of plants. During the vegetative period of development, higher temperatures will cause a more rapid rate of development, but more likely the response is linked with water shortage because of the increased rate in the use of soil water. This effect will be exaggerated if there is a shortage in soil water caused by limited rainfall or limited availability of irrigation water supplies. Ortiz et al. (2008) in an analysis of future wheat production in India based on projected climate scenarios found that there was a major shift in Indo-Gangetic Plains from a high potential, irrigated, low-rainfall mega-environment to a heat-stressed, irrigated, short-season production mega-environment. The significance of this shift is that this area currently accounts for 15% of the global wheat production and as much as 51% of the current area could be reclassified into this more stressful environment for wheat production causing a significant reduction in wheat production. These types of analysis need to be conducted for all of the food and feed growing regions of the world to determine the potential impact of climate change on production. These effects are due to the projected scenarios and do not include the potential impacts from extreme events.

Extreme events in temperature will have their greatest effect if they occur just prior to or during critical pollination phases of the crop. The impact is not universal across all crop species because of the duration and timing of the pollination phase of crop development and has been observed through numerous experimental studies throughout the world. Crop sensitivity and ability to compensate during later improved weather, will depend on the synchrony of anthesis in each crop: maize for example has a highly compressed phase of anthesis, while spikelets on rice and sorghum may achieve anthesis over a period of a week or more. Soybean, peanut, and cotton will have several weeks over which to spread the success of reproductive development. For peanut (and presumably other legumes) the sensitivity to elevated temperature for a given flower, extends from 6 days prior to opening (pollen cell division and formation) up through the day of anthesis. Therefore, several days of elevated temperature may affect fertility of many flowers whether still in their formative 6-day phase or just achieving anthesis. In addition the first 6 h of the day were more critical during which the pollen dehiscence, pollen tube growth and fertilization occur. (Hatfield et al, 2008)

High temperatures in rice, the reproductive processes that occur within 1-3 h after anthesis (dehiscence of the anther, shedding of pollen, germination of pollen grains on stigma, and elongation of pollen tubes) are disrupted by daytime air temperatures above 33ºC. Since anthesis occurs between about 9 to 11am in rice, exceeding such air temperatures may be already be common and may become more prevalent in the future. Pollination processes in other cereals maize and sorghum may have a similar sensitivity to elevated daytime temperature as rice. Rice and sorghum have the same sensitivity of grain yield, seed harvest index, pollen viability, and success in grain formation in which pollen viability and percent fertility is first reduced at instantaneous hourly air temperature above 33ºC and reaches zero at 40ºC. Diurnal max/min day/night temperatures of 40/30ºC (35ºC mean) cause zero yield. Extreme temperatures wil have negative impacts on grain yield. (Kim et al. (1996), Prasad et al. (2006))

Elevated temperatures above the optimum cause yield decreases due to temperature effects on pollination and kernel set in maize. Temperatures above 35ºC are lethal to pollen viability. In addition, the critical duration of pollen viability (prior to silk reception) is a function of pollen moisture content which is strongly dependent on vapor pressure deficit. There is limited data on sensitivity of kernel set in maize to elevated temperature, although in-vitro evidence suggests that the thermal environment during endosperm cell division phase (8 to 10 days post-anthesis) is critical. A temperature of 35ºC compared to 30ºC during the endosperm division phase dramatically reduced subsequent kernel growth rate (potential) and final kernel size, even if placed back in 30ºC. Temperatures above 30ºC increasingly damaged cell division and amyloplast replication in maize kernels and thus reduced grain yield. Leaf photosynthesis rate of maize has a high temperature optimum of 33 to 38ºC with minimal sensitivity of quantum efficiency to elevated temperature, although photosynthesis rate is reduced above 38ºC. An evaluation of high temperature effects on sweet corn in a controlled environment chamber, found the highest photosynthetic rate was at temperatures of 25/20 while at 40/35°C (light/dark) the photosynthetic rate was 50-60% lower. There was also a gradual decline in photosynthetic rate for each 1°C increase in temperature. These extreme events in temperature will negatively impact crop yield and will be increased in areas which are subjected to increased probability of variable precipitation. (Ben-Asher et al. (2008), Fonseca and Westgate (2005))

Analysis of the impact of climate change during the period from 1981 to 2005 in semiarid northwest region of China showed there was a change in phenology of wheat with an increase in crop yields at both the low altitude and high altitude locations (Xiao et al., 2008). They projected based on the expected warming trends a 3.1% increase in yields at the low altitude sites and a 4.0% increase at the high altitudes. Impact of climate change on rice yield in Japan was evaluated using the PRYSBI model (Process-based Regional scale Rice Yield Simulator with Bayesian Inference) with model parameters of the PRYSBI were calibrated with based on historical data on rice yield and climate variables in each prefecture of Japan and the model can reproduce yield by prefecture with the precision of 0.2t/ha (Yokozawa et al., 2009). In the PRYSBI, sterility and growth limitation due to extremely high and low temperature during yield formation period is explicitly simulated. In all regions, as temperature increases, inter-annual variability of rice yield is expected to increase due to the increase in occurrence of sterility caused by heat stress. This trend is especially significant in Tokai, Chubu, Kansai regions, where the intensification of the Pacific high pressure is expected to cause more frequent very hot summer under climate change. While the national average of rice yield will not change or slightly increase with the temperature increase smaller than 3 °C, the regional average of rice yield will decrease with larger temperature increase except in Hokkaido/Tohoku region. Shift of planting date is expected to be an effective adaptation in the north and east regions of Japan, while introduction of heat tolerant varieties will be favorable in the west and south regions of Japan. (Yokozawa et al., 2009)

Drought causes yield variation and in Europe the historical yield records show that drought is the primary cause of interannual yield variation (Hlavinka et al., 2009). Water supply for agricultural production will be critical to sustain production and even more important to provide the increase in food production required to sustain the world’s growing population. With glaciers retreating due to global warming and El Niño episodes, the Andean region faces increasing threat on water supply. With most of the precipitation coming in 3-4 months, the glaciers plays a temporal buffer by stocking precipitations in ice and snow and redistribution of the water by melting during the dry season. The glaciers recession reduces the buffering role of the glaciers, hence inducing a double threat: more floods during raining season and more water shortage during the dry season. Physically, the glaciers are holding rocks and other debris. With retreating of glaciers, such debris are now exposed and could lead to debris flows after heavy rainfalls or after earthquakes. The recession of the glaciers also induces the formation of high altitude lakes and some of them include a risk of being suddenly released after earthquakes, of if an avalanche creates a GLOF. The risk of collapse of such dams can have drastic consequences. (Silverio and Jaquet, 2005; Vuille et al., 2008; Zemp, 2008)

The economies of many developing countries rely heavily on agriculture; dominated by small-scale and subsistence farming. People’s livelihoods in this sector are especially exposed to weather extremes (Easterling, W and Apps, M, 2005). The majority of households produce maize in many African countries, but only a modest proportion sell it – the great majority eat all they produce. In Kenya for example, nearly all households grow maize, but only 36% sell it, with 20% accounting for the majority of sales. This pattern sees a growing inequality of income which is likely to continue as farms get smaller due to population growth and environmental degradation (FAO, 2009). Both such famers and their governments have limited capacity for recovery (Easterling, W and Apps, M, 2005). Farmers do not usually have insurance although micro insurance is increasingly available.

The initial obvious impact is a shortage of food for those entirely dependent on their own produce for their food supply, and those whose cash livelihood depends on their own food crops. Crop-failure is a key driver for rural urban migration, which is expected to be exacerbated under climate change. For example: since 1970, Malawi has faced increasing frequency and severity of drought and flood events, less seasonal rain and higher temperatures. A hybrid drought tolerant maize variety has been promoted, but requires expensive inputs such as chemical fertiliser, which is unaffordable for small holder farmers unable to find cash employment. These combined production factors create significant hardship for smallholder farmers (ActionAid, 2006). A more complex impact followed Cyclone Nargis in the Ayeyarwaddy delta region of Myanmar. The disaster's convergence with the global financial crisis has seen the rural economy collapse as credit has been withdrawn. Food security is again a significant concern (Stone, 2009).

Subsistence farmers who have a marginal existence under normal conditions, are probably the most severely impacted by climate and weather events. The most vulnerable to food price increases are poor, urban residents in food-importing developing countries; the landless poor and female-headed households are also particularly vulnerable (FAO, 2008). (Global food price increases are burdened disproportionally by low-income countries, where many people spend up to 50% of their income on food (OECD-FAO, 2008)). In some locations women and girls bear the initial brunt of food scarcity, which is both a result of, and contributes to, systemic gender inequality (Vincent et al., 2008).

4.4.2.4. Human Settlements, Industry and Infrastructure

Most urban centres in sub-Saharan Africa and in Asia have no sewers (Hardoy, Mitlin and Satterthwaite, 2001). Sanitation infrastructure is the main determinant of the contamination of urban floodwater with faecal material, presenting a substantial threat of enteric disease (Ahern et al., 2005). In Andhra Pradesh, India, a heat wave killed more than 1,000 people – mostly labourers working outside in high temperatures in smaller urban settlements (Revi, 2008).

Flooding (also leading to disease), landslides (UN/POP/EGM-URB/2008/16), Heatwaves (Kovats and Aktar 2008) are important hazards for this sector. It is well documented that, in most cities, the urban poor live in the most hazardous urban environments – for instance on floodplains or other areas at high risk of flooding or unstable slopes (Hardoy, Mitlin and Satterthwaite, 2001). Worldwide, about one billion live in informal settlements, and this proportion is growing at about twice the rate of formal settlements.

Climate change is likely to bring ever-increasing numbers of accidental deaths and serious injuries and increasingly serious damages to people's livelihoods, property, environmental quality and future prosperity – especially the urban poor in informal settlements (UN/POP/EGM-URB/2008/16).

A large proportion of those in informal settlements are especially susceptible to harm with limited ability to recover. Groups especially impacted include infants and older groups who are less able to cope with heat waves, and less able to escape floodwaters. Those who work outside without heat protection are also very vulnerable (UN/POP/EGM-URB/2008/16).

Poorer groups get hit hardest by this combination of greater exposure to hazards (e.g., a high proportion living on unsafe sites) with no or limited hazard-removing infrastructure, and high vulnerability due to makeshift housing with less capacity to cope due to a lack of assets, insurance, and marginal livelihoods, with less state support and limited legal protection. Low-income groups also have far less scope to move to less dangerous sites (UN/POP/EGM-URB/2008/16). Informal settlements are found in all regions, for example there are some 50 million people in such areas in Europe (UNECE 2009).

Coastal areas are among the world’s most vulnerable to climate extremes, such as Sea Level Rise (SLR) and other events (e.g. tropical storms and cyclones and related storm surges), the intensity and frequency of which is projected to increase. Moreover, as the size/permanence of coastal communities and infrastructure has increased very significantly over recent decades, affecting the ability of coastal systems to respond effectively to SLR and other extreme climate events, the exposure of coastal communities/assets is growing at an ever increasing rate. The severity of the impacts will depend on the rate of SLR, with rapid SLR likely to impact more severely natural systems and amplify the potential economic losses/costs of adaptation. Coastal landforms (beaches, seacliffs, estuaries, lagoons, deltas) are highly likely to suffer increased rates of erosion, while coastal ecosystems, such as coastal wetlands, coral reefs and seagrasses may also be severely affected. Economic activities in coastal areas that may be at threat from SLR and other extreme events include among others transportation (ports and other coastal infrastructure, e.g. airports, railways and roads) and tourism (due to beach erosion and threat to coastal tourism infrastructure). Small island states, particularly SIDS, are likely to be very severely affected; in some cases, and depending on the SLR scenarios, there might even be a need for permanent population evacuation. In some coastal settings and landforms (e.g. deltas and coastal wetlands), SLR will be further exacerbated by (i) land subsidence triggered by natural processes (e.g. sediment auto-compaction) and/or human-induced interference (e.g. extraction of groundwater/hydrocarbons); (ii) diminishing sediment supply due e.g. to river damming and other management schemes. (The Copenhagen Diagnosis (2009), Lenton et al. (2009), Cai et al. (2009), Ericson et al. (2006), Woodroffe (2008))

Slope failure risk is expected to increase in future at many places, since increase in frequency/intensity of strong rainfall is projected by climate models. Slope failure risk in Japan under the changed precipitation was evaluated for the period around 2050 with spatial resolution of 1km^2. With using spatial data on daily precipitation, geography, geology, and landuse, slope failure probability in each grid cell was calculated first. Then, with multiplying economic value of each grid cell, expected economic loss due to slope failure (return period: 50 years) under the changed climate condition was calculated. Grid cells with high slope failure risk is expected to distribute from the top to the skirts of mountainous area. Especially, in the south Hokkaido region, the coast of Japan Sea from Hokuriku region to Chugoku region, and median tectonic zone from Tokai region through Shikoku region, increase in slope failure risk is most significant. In some prefectures (Tochigi, Gumma, Saitama, Toyama, Ishikawa, Fukui, Hiroshima, and Kagoshima), area with high expected economic loss due to slope failure concentrates. Therefore, prioritized implementation of adaptation measures will be needed in those prefectures. (Kawagoe and Kazama,2009)

Throughout most of the 20th century, North Atlantic oscillation (NAO) correlates with winter precipitation and river flow regimes for the three main international Iberian river basins, namely the Douro (north), the Tejo (centre) and the Guadiana (south). The impact of the NAO on winter river flow was quantified in terms of total Spanish potential hydroelectricity production. The important control exerted by the NAO and the recent positive trend in the NAO index contribute to a significant decrease in the available flow, and therefore, hydropower production in the Iberian Peninsula. (Trigo et al., 2004)

Climate warming leads to permafrost degradation, the 40-80-cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost (Sherstyukov, 2009). Changes in permafrost damage the foundations of buildings and disrupt the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10-12% in 20-25 years, with permafrost borders moving 150-200 km northeast (Anisimov et al., 2004).

Approximately 10% of global GDP is spent on recreation and tourism, being a major source of income and foreign currency in many developing countries (Berrittella et al, 2006). The tourism sector is highly sensitive to climate, since climate is the principal driver of global seasonality in tourism demand (Maddison, 2001; Lise and Tol, 2002). It is also widely recognized that extreme weather events like floods, excessive heat, and windstorms, affect human life and environments more than changes in the mean climate, and therefore a potential increase in extreme events may play an important role on tourist decisions (Yu et al., 2009).

The distribution of global tourism is expected to shift polewards due to increased temperatures associated with climate change (Amelung et al., 2007). Parts of the Mediterranean, a very popular summer tourist spot, may become too hot in summer but more appealing in spring and autumn (Hein et al., 2009). More temperate tourist destinations are predicted to become more attractive in summer. Length and quality of climate-dependent tourism seasons (e.g., sun-and-sea or winter sports holidays) are expected to change in different areas, with considerable implications for competitive relationships between destinations and therefore the profitability of tourism enterprises (Amelung et al, 2007; Bigano et al, 2007). A changing trend on climate extremes will impact the tourism sector (Scott et al., 2008), and requires examination of nature and severity of physical risks impacting tourism resources (e.g. biodiversity, water supply, snow reliability) and infrastructure (e.g., coastal resorts), business and regulatory risks (e.g., changes in insurance coverage), or market risks (e.g., changes in international competitiveness linked with comfort temperatures).

There are three broad categories of climate extreme impacts that can affect tourism destinations, their competitiveness and sustainability: (a) direct impacts on tourist infrastructures (hotel, access roads, etc), on operating costs (heating-cooling, snowmaking, irrigation, food and water supply, evacuation and insurance costs), on emergence preparedness requirements, and on business disruption (e.g., sun-and-sea or winter sports holidays); (b) indirect environmental change impacts of extreme events on biodiversity and landscape change (eg. coastal erosion), which are likely to be largely negative on quality of tourism attractions and perception of a location; and (c) tourism adverse perception to particular touristic regions after occurrence of the extreme event itself, questioning a tourist destination in a longer-term (annual basis). It is not unlike that as result of adverse weather conditions or occurrence of an extreme event is produced a reduced confidence in the area by tourists during the follow up season. Apart from extreme events, long-term climate change effects (e.g. sea level rise and coral bleaching) may produce large impacts on some tourist destinations. Capacity to recover is likely to depend on the degree of dependence on tourism with diversified economies being more robust (Ehmer and Heymann, 2008). Low lying coastal areas and areas currently on the edge of the snow line may have limited alternatives. Some ski resorts will be able to adapt using snowmaking which has become an integral component of the ski industry in Europe and North America, although at expenses of high water consumption (Elsasser and Bürki, 2002). The complex nature of the interactions that exist between tourism, the climate system, the environment and society, makes difficult to isolate the direct observed impacts of climate change upon tourism activity (Rezenweig et al., 2007).

In some regions, the main impact of extreme events in tourism will be decline in revenue, with loss of livelihoods for those working in the sector, and provokes mistrust on tourism and operating companies in the affected area (Hamilton et al., 2005; Scott et al., 2008; Hein et al., 2009). Regional projections in the frequency or magnitude of certain weather and climate extremes (e.g. heat waves, droughts, floods, tropical cyclones; see chapter 3) provide a qualitative understanding of regional impacts on tourism activities (Table 2). The vulnerable hotspot regions in terms of extreme impacts of climate change on tourism includes the Mediterranean, Caribbean, small island of the Indian and Pacific oceans, Australia and New Zealand, (see Figure 4-12; Scott et al., 2008). Direct and indirect effects of extremes in these regions will vary greatly with location (Gössling and Hall, 2006a,b; Wilbanks et al., 2007).

[INSERT FIGURE 4-12 HERE:
Figure 4-12: Climate change vulnerability hotspots in the tourism sector (Scott et al., 2008).]

A potential range of climate extreme impacts on tourism regions and activities can be pointed out.

Tropics: Increase cyclone intensity, with wind speeds expected to increase up to 20% (Preston et al, 2006). In the Caribbean, reduced tourist amenity as beaches erode with sea level rise, and degraded snorkeling and scuba activities due to coral bleaching (Uyarra et al, 2005). Increasing incidence of vector-borne diseases as result of increased temperatures and humidity will all impact tourism to varying degrees in the tropics (Tong and Hu, 2001). For example, Ross River fever outbreaks in Cairns, Australia, have a significant impact on the local tourist industry.

Small island states are dependent on tourism, and the tourism infrastructure that lies on the coast is threatened by climate change (Berrittella et al., 2006). Sea level rise since 1880 with an average rate of 1.6 mm/year (Bindoff and Willebrand 2007) poses in risk many touristic resorts of small islands in the Pacific and Indian oceans (Scott et al., 2008).

Alpine regions: Warming temperatures will raise the snow line elevation (Elsasser and Bürki, 2002; Scott et al., 2006). In Switzerland only 44% of ski resorts will be above the 'snow-reliable' altitude by approximately 2030, as opposed to 85% today, whereas in Austria, many ski areas will suffer from reduced snow reliability (Elsasser and Bürki, 2002).

Mediterranean countries: More frequent heat waves and tropical nights in summer may lead to exceeding comfortable temperature levels and reduce the touristic flow by 2060 (Hein et al., 2009). Increase on travelling and holidays during transition seasons (spring and autumn; Perry, 2003, Esteban Talaya et al., 2005). Change on the tourist behavior, decreasing the stay period, delaying the travel decision, changing the selection of destination. Northern European countries are expected to become relatively more attractive closing the gap on the currently popular southern European countries (Hamilton et al., 2003)

There are major regional gaps in understanding how climate change may affect the natural and cultural resources in Africa and South America that prevents for further insight on their impacts on tourism activities (Scott et al., 2008).

[INSERT TABLE 4-13 HERE
Table 4-13: Identification of extreme impacts affecting the tourism sector by regions. Sources: IPCC 2007; Ehmer and Heymann, 2008; Scott et al., 2008]

4.4.2.5. Human Health, Well-Being, and Security

The largest research gap is a lack of information on impact outcomes themselves in developing countries in general. This includes the mortality/morbidity data and information on other contributing factors such as nutritional status or access to safe water, medical facilities. Only limited number of places in developing countries has been investigated. As Byass (2009) showed, among 731 of health and climate change subjects, only 31 (4.2%) was on Africa. The lack of information is inherent in developing countries, where public health infrastructure is poor and where the impact would be hardest due to both severe hazards and lower coping capacity. Within the developing countries, lower socio-economic status usually worsens the vulnerability.

Research conducted include those of heat wave, flood, extreme weather (heavy rain followed by drought, for example), and cyclone. These three extreme weather events can occur even if climate change did not occur. However, the frequency may be higher when the global warming occurs.

Heat waves have affected developed countries, as exemplified by 2003 European heat wave. Most people do not think that heat extremes can claim casualties in tropical countries. Hajat et al. (2005) reported, however, that heat extremes affected Delhi, India. This example suggests that the effect of heat extremes on developing countries would be underestimated. Hajat et al. (2005) also demonstrated that the mortality pattern due to heat in Delhi was different from that of other developed countries. In this regard, more researches should be conducted in developing countries.

Floods directly cause deaths, injuries, followed by infectious diseases (such as diarrhea) and malnutrition due to crop damage. In Dhaka, Bangladesh, the severe flood in 1998 caused diarrhea during and after the flood, and the risk of non-cholera diarrhea was higher for those with lower education level and not using tap water (Hashizume M et al., 2008). In 2002 report, WHO assumed that countries with 6,000+ US dollars of per capita GDP. On the contrary, diarrhea as well as injuries occurred after a 2002 flood in Germany, one of the developed countries (Schnitzler J, et al., 2007). It may not always be true, but floods can increase the patients of malaria in some cases. In Mozambique, the incidence of malaria increased by 4 to 5 times after the flood in 2000 (compared with non-disaster periods) (Kondo, et al., 2002).

In 1991, 138,000 people died due to a cyclone in Bangladesh. The risk factors for mortality were those who did not reach shelters, those under 10 years of age, and women older than 40 years (Bern C et al, 1993). The authors discussed that more effective warning system and better access to cyclone shelters were necessary.

Drought is a trigger for human ignited forest fires leading to widespread deforestation and carbon emissions. (Field et al. (2009), Van Der Werf et al. (2008), Costa and Pires (2009), D'almeida et al. (2007), Phillips et al. (2009)).

In western part of North America in the recent 30 years the area affected by forest fires increased twofold, and in the coming 100 years under expected warming it will further increase by 80%. Modeling of forest fires in Siberia shows that the temperature rise from 9,80C to 15,30C may result in the fact that a number of years with severe fires will increase twofold, an area affected by forest fires will be increasing by almost 15% per year and timber resources will reduce by 10%.

4.5. Regionally Based Aspects of Vulnerability, Exposures, and Impacts

4.5.1. Introduction and Overview

These regional sections are about climate change and climate-related disasters within the context of other issues and trends.

The material should deal with extreme climate events and impacts. In doing this it would consider exposure of humans and their activities to the climatic phenomenon, the vulnerability of what is exposed to the phenomenon and the resulting impacts. There is a strong interest in the observed trends in climatic events, exposure, vulnerability and impacts and the role of climate change in any observed trends.

Each region will likely have its own priorities and these will help structure the individual sections.

4.5.2. Africa

Africa is the second largest continent, with area of 30,221,532 km^2, one third of which is covered by drylands (Sahara, Namib). The estimated total population in Africa now (2010) is around one billion. The Africa's climate ranges from the humid tropics to the hyper-arid Sahara. Climate exerts a significant control on the day-to-day economic development of Africa, particularly in traditional rain fed agriculture and pastoralism, and water resources, at all scales – from regional, to local and household scales. Observed warming trends are consistent over the continent with an average increase of 0.74°C over the period 1906-2005 (see Christensen et al., 2007), although these changes are not uniform over the continent (Boko et al., 2007). In general terms, minimum temperatures registered a major increase during the last decade, whereas minor increases were observed in maximum or mean temperatures (Conway et al., 2004; Kruger and Shongwe, 2004). Climate model projections estimate a temperature increase of 0.2°C per decade over the 21st century within the range of the SRES scenarios (Christensen et al., 2007). The expected warming trends will mean as direct impact projections (Boko et al., 2007): an increase of arid and semi-arid land, increase in the number of people exposed to increased water stress, decrease of yield from rain-fed agriculture in some countries, and a widespread increase in evapotranspiration and reduction in runoff and in ecosystem net primary production (Delire et al. 2008).

Extreme events, such as droughts and floods, are known to have a major human and ecological impact in this continent. However, there is still limited information available on extreme events observed frequency and projections (Christensen et al., 2007, Chapter 3 this SREX report), despite frequent reporting of such events, including their impacts.

[INSERT FIGURE 4-13 HERE:
Figure 4-13: People affected by natural disasters from 1971-2001.]

Droughts and heat waves
The number of hot spells has increased in southern and western Africa over last decades, together and the number of extremely cold days has decreased (New et al., 2006). Droughts have mainly affected the Sahel, the Horn of Africa

and Southern Africa, particularly since the end of the 1960s (Richard et al., 2001; L'Hôte et al., 2002; Brooks, 2004; Christensen et al., 2007; Trenberth et al., 2007).

One of the main consequences of a multi-year drought periods is severe famine, such as the one associated with the drought in the Sahel in 1980s, causing many casualties and high economic losses. It is estimated that one-third of the people in Africa live in drought-prone areas and are vulnerable to the direct impacts of droughts (famine, death of cattle, soil salinisation), cholera and malaria (Few et al., 2004). Adaptation strategies that are applied by pastoralists in times of drought include the use of emergency fodder, culling of weak livestock for food, and multi-species composition of herds to survive climate extremes. During drought periods, pastoralists and agro-pastoralists change from cattle to sheep and goat husbandry, as the feed requirements of the latter are lower (Seo and Mendelsohn, 2006b). The pastoralists' nomadic mobility reduces the pressure on low-capacity grazing areas through their cyclic movements from the dry northern areas to the wetter southern areas of the Sahel (Boko et al., 2007). However, consecutive dry years with widespread disruption are reducing the ability of the society to cope with droughts by providing less recovery and preparation time between events (Adger, 2002). Moreover, land desertification and agricultural disruption together with shoreline erosion and coastal flooding, results from climate change, is projected to drive human migration.

Extreme rainfall events and floods

In parts of southern Africa, a significant increase in heavy rainfall events has also been observed, including evidence for changes in seasonality and weather extremes (Groisman, 2005; New et al., 2006). In southern Africa, where no long-term rainfall trend has been noted, increased inter-annual variability has been observed in the post-1970 period, with higher rainfall anomalies and more intense and widespread droughts reported (e.g., Richard et al., 2001; Fauchereau et al., 2003). Further north, in the Sahelian area, a sixty years rainfall record indicate, along a West-East transect, a trend towards an increase in drier years in the western regions (Ali and Lebel, 2008), whereas, specially during 1993-2006, a higher proportion of wet years is being registered in eastern Sahel (Lake Chad area).

Even countries located in dry areas have not been flood-free. In the arid and semi-arid areas of Horn of Africa countries, extreme rainfall events are often associated with a higher risk of vector- and epidemic diseases as malaria, dengue fever, cholera, Rift Valley fever (RVF), and hantavirus pulmonary syndrome (Anyamba et al., 2006; McMichael et al., 2006). This arthropod-borne viral disease (Geering et al., 2002) affects both humans and domestic ruminants. The periods of extreme rainfall and recurrent floods seem to correlate with El Niño/Southern Oscillation (ENSO) events (e.g. 1982-63, 1997-98, 2006-07). When such events occur, important economic and human losses result. In 2000, floods in Mozambique, particularly along the Limpopo, Save and Zambezi valleys, resulted in 700 reported deaths and about half a million homeless. The floods had a devastating effect on livelihoods, destroying agricultural crops, disrupting electricity supplies and demolishing basic infrastructure (Osman-Elasha, 2006). However, floods can be highly beneficial in African drylands (e.g. Sahara and Namib deserts) since the produced floodwaters infiltrate and recharge alluvial aquifers along ephemeral river pathways, extending water availability to dry seasons and drought years (Morin et al., 2009; Benito et al., 2010), and supporting riparian systems and human communities (e.g. Walvis Bay in Namibia with population 65,000).

The water sector is strongly influenced by, and sensitive to, periods of prolonged climate variability in a continent with limited water storage infrastructures. Natural water reservoirs such as lakes have experienced high interannual water level fluctuations, in particular since the 1960s, probably owing to periods of intense droughts followed by increases in rainfall and extreme rainfall events in late 1990s (e.g., in Lakes Tanganyika, Victoria and Turkana; see Riebeek, 2006). Large changes in hydrology and water resources linked to climate variability have led to water stress conditions to human and ecological systems in southern Africa (Schulze et al., 2001; New, 2002), south-central Ethiopia (Legesse et al., 2003), Kenya and Tanzania (Eriksen et al., 2005) and more wider, over the continent (de Wit and Stankiewicz, 2006; Nkomo et al., 2006). In terms of water availability, 25% of the contemporary African population experience high water stress, whereas 69% of the population live under conditions of relative water abundance (Vörösmarty et al., 2005). However, this relative abundance does not take into account access to safe drinking water and sanitation, which effectively reduces the quantity of freshwater available for human use. Despite the considerable improvements in access to freshwater in the 1990s, only about 62% of the African population had access to improved water supplies in 2000 (WHO/UNICEF, 2000).

Dust windstorms
Atmospheric dust is a major element of the Saharan and Sahelian environments. The Sahara Desert is the world's largest source of airborne mineral dust, that is transported large distances, traversing northern Africa and adjacent regions and depositing dust in other continents (Osman-Elasha, 2006, Moulin et al., 1997). Dust storms have negative impacts on agriculture, eroding fertile soil, uprooting of young plants, burying water canals, houses and other properties, and causing respiratory problems. Meningitis transmission, associated with dust in semi-arid conditions and overcrowded living conditions, may increase with climate change as arid and dusty conditions spread across the Sahelian belt of Africa. (DFID, 2004).

Adaptation
Adaptation strategies that are applied by pastoralists in times of drought include the use of emergency fodder, culling of weak livestock for food, and multi-species composition of herds to survive climate extremes. During drought periods, pastoralists and agro-pastoralists change from cattle to sheep and goat husbandry, as the feed requirements of the latter are lower (Seo and Mendelsohn, 2006b). The pastoralists' nomadic mobility reduces the pressure on low-capacity grazing areas through their cyclic movements from the dry northern areas to the wetter southern areas of the Sahel (Boko et al., 2007). However, consecutive dry years with widespread disruption are reducing the ability of the society to cope with droughts by providing less recovery and preparation time between events (Adger, 2002).

African women are particularly known to possess indigenous knowledge which helps to maintain household food security, particularly in times of drought and famine.

4.5.3. Asia

Destructive extreme events are commonplace in Asia. Changes (mostly increases) in the frequency and/or intensity of extreme weather events in Asia have been reported (Cruz et al., 2007).

Temperature extremes
Significantly longer heat wave duration has been observed in many countries of Asia, as indicated by pronounced warming trends and several cases of severe heat waves (Lal, 2003; Zhai and Pan, 2003; Ryoo et al., 2004; Batima et al., 2005a; Cruz et al., 2006; 2007; Tran et al., 2005). Increase of heat wave duration and severity was observed, among others, in Asian part of Russia, Mongolia, China, Japan, India, also decreases of cold extremes (cold waves) were noted (e.g., in Mongolia and Japan).

During 1955–2007 averaged over the Asia-Pacific Network (APN) region, annual frequency of cool nights (days) has decreased by 6.4 days/decade (3.3 days/decade), whereas the frequency of warm nights (days) has increased by 5.4 days/decade (3.9 days/decade). The change rates in the annual frequency of warm nights (days) over the last 20 years (1988–2007) have exceeded those over the full 1955–2007 period by a factor of 1.8 (3.4). Averaged over the APN region, annual mean maximum and minimum temperatures have increased by 0.17 °C/decade and 0.24 °C/decade since the mid-1950s, respectively (Gwangyong Choi *et al.*, 2009).

In Japan, the numbers of days with abnormally low air temperature decreased in recent decades and those with extremely high air temperature (>35°C) strikingly increased (Kurihara 2007). In the summer of 2003, the subtropical high was much stronger than normal and extended further west covering most of southern China for a long period of time. This led to severe heat wave with many hot days over that region. (Zhang *et al.,* 2008)

Rising temperatures and extreme weather events caused decline of the crop yield in many countries of Asia and adversely affected human health (Cruz et al., 2007).

Droughts
Increasing frequency and intensity of droughts has been observed in many parts of Asia, causing water shortage, crop failures, mass starvations, and wild fire. In Mongolia, in 1999-2002, a drought affected 70% of grassland and killed 12 million livestock. Increased droughts are attributed largely to a rise in temperature, particularly during the

summer and normally drier months, and during ENSO events (Duong, 2000; PAGASA, 2001; Lal, 2002, 2003; Batima, 2003; Gruza and Rankova, 2004; Natsagdorj et al., 2005). The number of days without precipitation show a rising trend in Japan (Kimoto et al. 2005).

Drought has significant adverse effect on the socioeconomic, agricultural, and environmental conditions. During drought, severe water-scarcity results in a region due to insufficient precipitation, high evapotranspiration, and over-exploitation of water resources and/or combination of these parameters (Bhuiyan *et al.,* 2006).

A study on esophageal cancer (EC) mortality rate and selected climate variables showed that high EC mortality mostly occurred in areas with high Drought Index. Correlation and regression analyses also show weak negative correlation between precipitation and EC mortality ($p<0.001$), and weak positive correlation between Drought Index and EC mortality ($p<0.001$). The study suggests that drought plays a role in the occurrence and development of EC in China, however, other environmental, biological and genetic factors should not be ignored (Kusheng Wu *et al.,* 2007)

About 15% (23 million ha) of Asian rice area experiences frequent yield loss due to drought (Widawsky and O'Toole, 1990). The problem is particularly severe in Eastern India, with more than 10 million ha of drought-prone fields (Pandey et al., 2000). Even when the total rainfall is adequate, shortages at critical periods reduce yield (Kumar *et al.,* 2007).

Keil *et al.* (2008) summarized that crop production in the tropics is subject to considerable climate variability that is mostly attributable to the El Niño-Southern Oscillation (ENSO) phenomenon (Salafsky 1994; Amien et al. 1996; Datt and Hoogeveen 2003). In Southeast Asia, El Niño is associated with comparatively dry conditions: 93% of droughts in Indonesia between 1830 and 1953 occurred during El Niño years (Quinn et al., 1978). In four El Niño years between 1973 and 1992, the average annual rainfall amounted to only around 67% of the 20 year average in two major rice growing areas in Java, Indonesia, causing a yield decline of approximately 50% (Amien et al. 1996). There is evidence that, in concert with global warming, the frequency and severity of extreme climatic events will increase during the twenty-first century, and the impacts of these changes will notably hit the poor (McCarthy et al. 2001).

Lowland rice production in the Mekong region is generally low because crops are cultivated under rainfed conditions and often exposed to drought. In Cambodia, severe drought that affect grain yield mostly occurs late in the growing season, and longer duration genotypes are more likely to encounter drought during grain filling (Tsubo *et al.,* 2009).

Intense precipitation and floods

Generally, there has been an increase in frequency and/or amplitude of heavy rains and floods, in number of days with high-intensity precipitation in many parts of Asia, e.g. in West and South China, Japan, Western Asian Russia, South-East Asia (Vietnam, Philippines, Cambodia), but not ubiquitously. Increase in heavy precipitation has caused severe floods, landslides, and debris and mud flows, even in some areas where the number of rainy days and total annual amount of precipitation decreased (Khan et al., 2000; Shrestha et al., 2000; Izrael and Anokhin, 2001; Mirza, 2002; Kajiwara et al., 2003; Lal, 2003; Min et al., 2003; Ruosteenoja et al., 2003; Zhai and Pan, 2003; Gruza and Rankova, 2004; Zhai, 2004). However, in some areas the frequency of extreme rainfall has exhibited a decreasing tendency (Manton et al., 2001; Kanai et al., 2004) – e.g. there has been a decrease in extreme precipitation in Northern China. Over Siberia, there has been a decrease in heavy rains but 50-70% increase in surface runoff.

There are no systematic, regional trends over the study period in the frequency and duration of extreme precipitation events in Asia-Pacific Network. Statistically significant trends in extreme precipitation events are observed at fewer than 30% of all weather stations, with no spatially coherent pattern of change, whereas statistically significant changes in extreme temperature events have occurred at more than 70% of all weather stations, forming strongly coherent spatial patterns (Gwangyong Choi *et al.*, 2009).

Significant changes in precipitation over the Yangtze River Basin were found by (Tong Jiang, *et al.,* 2008). Changes in the monthly precipitation in spring and summer, from April to August, some of which are statistically significant, are of direct importance to seasonal flood hazard. The significant precipitation rise detected in June, July, and August tends to aggravate the flood hazard. More precipitation falls in intense events at the expense of moderate and weak events. The results by Ning Liang *et al.* (2009) for South China show that both the annual and summer extreme precipitation events have obvious inter-decadal variations and have increased significantly since the early 1990s.

Analysis of daily rainfall data over central India shows significant rising trend in the frequency and the magnitude of extreme rain events and significant decreasing trend in the frequency of moderate events during the monsoon seasons from 1951 to 2000. A substantial increase in hazards related to heavy rain is expected over central India in the future (Goswami *et al.,* 2006).

Among most dramatic climate extremes are floods jeopardizing large areas of Bangladesh, China and India, and causing high human and material losses, e.g. 30 billion US$ and material damage in excess of 3500 during 1998 floods in China.

As noted in (Ministry of Environment and Forest Government of the People's Republic of Bangladesh, 2005), flood in Bangladesh is a frequently normal recurrent phenomenon. Four types of flooding occurring in Bangladesh are: flash floods caused by overflowing of hilly rivers in eastern and northern Bangladesh (in April-May and in September-November); rain floods caused by drainage congestion and heavy rains; monsoon floods in the flood plains of major rivers (during June-September) and coastal floods due to storm surges. In a normal year, 20-25% of the country is inundated by river spills and drainage congestions. Approximately 37%, 43%, 52% and 60% of the country is inundated with floods of return periods of 10, 20, 50 and 100 respectively. About 1.32 m ha of cropland is highly flood-prone and about 5.05 m ha moderately flood-prone. Devastating floods of 1987, 1988 and 1998 inundated more than 60% of the country. The 1998 flood alone caused 1,100 deaths, inundated nearly 100,000 sq-km, rendered 30 million people homeless, damaged 500,000 homes and caused heavy losses to infrastructure.

Significant upward trends in the discharge of the River Yangtze in summer (flood season) months in the middle and lower regions were also detected (Tong Jiang *et al.,* 2008). Annual events of peak lake stage and of severe floods have increased dramatically during the past few decades in Poyang Lake, South China. This trend is related primarily to levee construction at the periphery of the lake and along the middle of the Changjiang (Yangtze River), which protects a large rural population. These levees reduce the area formerly available for floodwater storage resulting in higher lake stages during the summer flood season and catastrophic levee failures. The most extreme floods occurred during or immediately following El Niño events (Shankman *et al.,* 2006).

The number of days with heavy rain over 100 mm or 200 mm show a rising trend in Japan (Kurihara 2007). Owing to meteorological and topographical characteristics, flood disasters caused by heavy rains occur frequently in Japan. About 70% of the land is mountainous and covered with forests. Rivers in Japan are generally short and steep, causing flash flooding with high concentrated peak discharges soon after an intense rainfall. The remaining 30% of the land is mostly alluvial plains where housing, farming and industries are densely concentrated, consequently increasing the vulnerability to flood disasters. The majority of the population lives in densely populated areas in downstream alluvial plains, forming mega-cities such as Tokyo and Osaka, where highly valued assets are concentrated. Thus, Japan inevitably suffers serious socio-economic damage once flood disasters occur (Ikeda *et al.,* 2006).

As reported by National Environment Commission in Royal Government of Bhutan (2006), all the major rivers in Bhutan originate from glaciers and glacial lakes of the higher Himalayas. Two dozens of glacial lakes are potentially dangerous. Not until the 1994 Glacial Lake Outburst Floods (GLOF) was this danger taken seriously. Now it is recognized that the Raphstreng and Thorthormi glaciers and lakes could become dangerous in about a decade unless mitigation measures are taken. The worst case scenario being that a combined GLOF of these two lakes could result in a flow of over 53 million cubic meters of water - that is more than twice the volume of the 1994 GLOF.

Tropical cyclones

Recent studies indicate that the frequency and intensity of tropical cyclones originating in the Pacific have increased over the last few decades (Fan and Li, 2005). In contrast, cyclones originating from the Bay of Bengal and Arabian

Sea have been noted to decrease since 1970 but the intensity has increased (Lal, 2001). In both cases, the damage caused by intense cyclones has risen significantly in the affected countries, particularly India, China, Philippines, Japan, Vietnam and Cambodia, Iran and Tibetan Plateau (PAGASA, 2001; ABI, 2005; GCOS, 2005).

An increase of 10 to 20%in tropical cyclone intensities for a rise in sea-surface temperature of 2 to 4°C relative to the current threshold temperature is likewise projected in East Asia, South-East Asia and South Asia (Knutson and Tuleya, 2004). Amplification in storm-surge heights could result from the occurrence of stronger winds,with increase in sea-surface temperatures and low pressures associated with tropical storms resulting in an enhanced risk of coastal disasters along the coastal regions of East, South and South-East Asian countries. The impacts of an increase in cyclone intensities in any location will be determined by any shift in the cyclone tracks (Kelly and Adger, 2000).

Other climate disasters

Grassland fire disaster is a critical problem in China due to global warming and human activity (Su *et al.*, 2004; Zhang *et al.*, 2006). The northwestern and northeastern China face more challenges for mitigation of grassland fire disasters than other regions due to broad territory combined with the effects of complex physiognomy. According to statistical analysis of historical data of grassland fire disaster from 12 northern China provinces between 1991 and 2006, grassland fire disasters have been increasing gradually with economic development and population growth. The increased grassland fire disasters had significant impacts on the national stockbreeding economy (Liu *et al.*, 2006).

4.5.4. Europe

Introduction

Europe has higher population density and lower birth rate than any other continent. There is a tendency for the population to decrease and to become aged. Life expectancy is high and increasing and child mortality is low and decreasing. Europe has warmed up more than global mean in the last hundred years (+0.90ºC vs 0.74ºC) and climate projections in both SRES A2 and B2 show warming in all seasons for the future (A2: 2.5 to 5.5ºC; B2: 1 to 4ºC, IPCC, 2007). Precipitation trends are more spatially variable with large north-south differences. Mean winter precipitation is increasing in most of Atlantic and northern Europe (Klein Tank et al., 2002), a key driver on floods particularly when associated with snow-melting from mountain areas (Benito et al., 2005). In the Mediterranean area, yearly precipitation trends are negative in the east, while they are non-significant in the west (Norrant and Douguédroit, 2006). Climate change involves losses and gains on natural resource and economic sectors basis. In the north, agriculture is temperature-limited and benefiting of climate change. In the south, agriculture is precipitation-limited and is adversely affected by climate change.

Heat waves

Summer heat waves have already become increasingly frequent in summer in most of Europe (Della-Marta et al., 2007) and have affected vulnerable segments of European society. During the 2003 heat wave, several tens of thousands of additional heat-related deaths were recorded in countries of southern Europe (see case study on 2003 heat wave). Urban heat island poses an additional risk to urban inhabitants, especially old, ill, and lonely. There is a mounting concern about increasing heat intensity in major European cities (e.g. London, Wilby, 2003a), since 25% of European population live in urban areas exceeding 750,000 inhabitants (UN, 2004).

Droughts and wildfires

Drought risk is a function of frequency, severity, and spatial extent of dry spell and the vulnerabity and exposure of population and economic activity. A clear trend in hydrological drought over the 20th century cannot be ubiquitously found (De Wit et al., 2007, Hisdal et al., 2001), and where it occurs (e.g. Iberian rivers) it cannot be attributed to climate change. Significant increase of dry spells has been observed in East Germany over the last five decades (Krysanova et al., 2008). However, climate model projections point out to a likely increase of drought risk in southern and central Europe (e.g., Semenov and Bengtsson, 2002; Voss et al., 2002; Räisänen et al., 2003, 2004; Frei et al., 2006). Increasingly pronounced low flow and drought conditions in Central Europe are projected (Hattermann et al., 2008, 2010; Huang et al., 2010). In sub-Aalpine areas, flow regime changes towards a nivalpluvial type with more pronounced low flow conditions in summer, and more pronounced high flow periods in winter.

Forest fire danger (length of season, frequency and severity) is very likely to increase in the Mediterranean (Santos et al., 2002; Pausas, 2004; Moreno, 2005; Pereira et al., 2005; Moriondo et al., 2006), where it may lead to increased dominance of shrubs over trees (Mouillot et al., 2002), but also in central, eastern and northern Europe (Goldammer et al., 2005; Kellomäki et al., 2005; Moriondo et al., 2006). This, however, does not translate directly into increased fire occurrence or changes in vegetation (Thonicke and Cramer, 2006).

The amount of water resources demanded by tourism may be in conflict with other needs along the Mediterranean, particularly during summer, when population is tripled by arrival of tourists, and the per capita water consumption grows to 350 litres/day, in comparison to the European mean of 150-200 litres/day. This economic activity is highly vulnerable to droughts, although due to the high economic revenues, adaptation has improved capability on water supply system to meet summer peak demands.

Coastal flooding

Coastal flooding is an important natural disaster, since many Europeans live near the coasts. Storm surges can be activated as results of wind-driven waves and winter storms (Smith et al., 2000), whereas long-term processes are linked to global mean sea-level rise (Woodworth et al., 2005). Ensemble modelling for the Baltic and southern North Sea indicate fewer but more extreme surge events (Lowe and Gregory, 2005) may be particularly harmful to prone erosion and flooding in estuaries, deltas and embayments (Woth et al., 2005).

The Netherlands is an example of a country that is highly susceptible to both sea-level rise and coastal flooding because 55% of its territory, where 60% of its population lives and 65% of its Gross National Product (GNP) is produced below sea level. Expected sea-level rise is projected to have impacts on Europe's coastal areas including land loss, groundwater and soil salinisation and damage to built property and infrastructures (Devoy, 2007; Nicholls and de la Vega-Leinert, 2008).

Hinkel et al. (2010) found that the total monetary damage in coastal areas of Member Countries of the European Union (EU) caused by flooding, salinity intrusion, land erosion and migration is projected to rise strongly, but adaptation can reduce the number of people flooded by two orders of magnitude and the total damage costs by factors 4 to 5.

Gale winds

Windstorms hit particularly, but not exclusively, coastal areas of Europe. Severe windstorms are associated with westerly flow (80%) occurring mainly during moderately positive NAO phase (Donat et al., 2009). The most frequent track runs along the north coasts of the British Isles onto the Norwegian Sea, but they may take meridional pathways affecting the northern Iberian Peninsula, France and central Europe. In the most severe extra-tropical windstorm month, December 1999, when three events struck Europe (Anatol - December 3, Denmark; Lothar - December 26, France, Germany and Switzerland; and Martin - December 28, France, Spain, and Italy), insured damage was in excess of €9 billion (Schwierz et al., 2009). Immense economic losses were generated by gale winds via effects on electrical distribution systems, transportation, and communication lines, private, and damage on buildings vulnerable elements (eg. lightweight roofs) and by trees falling on houses. A substantial increase in wind damage is not predicted, as can be extracted from a lack of consensus on projected wind speed changes over Europe (Barthod, 2003; Nilsson et al., 2004; Schumacher and Bugmann, 2006).

Flooding

Flooding is the most frequent and widely distributed natural risk in Europe. Economic losses from flood disasters in Europe have increased considerably in last decades due to climatic and non-climatic factors (Lugeri et al., 2010). The latter include socio-economic development, urbanization and infrastructure construction on traditional flood-prone area. Enormous flood impacts were due to a few individual flood events (e.g. 1997 floods in Poland and Czech Republic, 2002 flood in central Europe, and 2007 summer floods in UK). Flash floods from extreme precipitation are enhanced on impervious (urbanized areas) and on catchments after occurrence of a forest fire, due to soil hydrophobia and water repellence of some organic components. Particularly vulnerable are new urban developments and tourist facilities, such as camping, recreation areas (e.g. a large flash flood in 1997 in the Spanish Pyrenees, conveying a large amount of water and debris to a camping site, resulted in 86 fatalities; cf. Benito et al. 1998). Apart from new developed urban areas, flood damage will likely increase in relation to linear infrastructures, such as roads, railroads, and underground rails with inadequate drainage (Defra, 2004a; Mayor of London, 2005).

Two independent model-based studies show (Kundzewicz et al., 2010) that over approximately 30% of the area of Europe, the mean recurrence interval corresponding to what used to be the 100-year flood in the control period, is projected to decrease to below 50 years in the end of the 21st century. Projections (cf. Figure 4-14, from Dankers and Feyen, 2008) indicate that over much of Poland, Germany, Austria, Switzerland, France, and Italy the floods corresponding to the return period of 100 years in the control period are expected to become considerably more frequent. However, over much of Russia and Scandinavia, with snowmelt being important flood generating mechanism, floods corresponding to 100-year return period in the control period may become less frequent in the future. Increase of frequency of short-duration precipitation in most of Europe is likely to lead to increased risk of destructive flash floods and urban floods (EEA, 2004b).

[INSERT FIGURE 4-14 HERE:
Figure 4-14: Recurrence interval (return period) of today's 100-year floods (i.e. flood with a recurrence interval of 100 years during the period 1961-1990) at the end of the 21st century (2071-2100), for emissions scenario SRES A2. Source: Dankers and Feyen (2008).]

In glaciated areas of Europe glacial lake outburst floods (GLOFs) are the most important natural hazard, likely to produce immense socio-economic and environmental impacts in the affected areas. The highest GLOF hazard is related to glacial lakes dammed by young, unstable and unconsolidated moraines, and lakes in contact to the active ice body of a glacier (Damen, 1992). Intense lake level and dam stability monitoring on most glacial lakes in Europe helps prevent future major breach catastrophes. In case of flooding, major impacts are expected on infrastructure and settlements even at long distances downstream from the hazard source area.

Landslides

Climate change can modify frequency of landslides (Schmidt and Dehn 2000), which can impact on settlements and linear infrastructures. Observed trends in landslide occurrence point out to a decrease in activity in most regions, particularly in southern Europe, where revegetation on scree slopes enhanced cohesion and slope stability (Corominas et al. 2005). Reactivation of large movements usually occurs in areas with a groundwater flow and areas of river erosion. Earth flows and landslides may develop after intense precipitation events, likely to be enhanced by climate change.

Snow

Snow avalanches are an ever-present hazard with the potential for loss of life, property damage, and disruption of transportation. Increased use of mountain areas for recreation and tourism leads to an increased rate of mortality due to snow avalanches. During the period 1985–2005, avalanche fatalities have averaged approximately 120 per year in the European Alps (McClung and Schaerer, 2006). Increased winter precipitation may result in more than average snow depth or the duration of snow cover contributing to avalance formation (Schneebeli et al., 1997). Climate change impact on snow cover also includes decrease in duration, depth and extent and a possible altitudinal shift of the snow/rain limit (Beniston et al., 2003) Therefore, predictions about future avalanche activities under climate change is highly uncertain, depending on regional characteristics A potential increase of snow avalanches in high altitudes has impact on human activities (loss of life and infrastructures), andfurther impacts on mountain forest (Bebi et al., 2009.). Europe is the leading region in skiing industry, and there is a considerable sectoral vulnerability to mild winters. The ski industry in central Europe is projected to be disrupted by significant reductions in natural snow cover, especially at lower elevations (Kundzewicz and Parry, 2001, Alcamo et al., 2007). Hantel et al. (2000) found that at the most sensitive elevation in the Austrian Alps (below 600 m in winter and 1400 m in spring) and with no snowmaking adaptation considered, a 1°C rise leads to four fewer weeks of skiing days in winter and six fewer weeks in spring. Beniston et al. (2003) projected that a 2°C warming with no precipitation change would reduce the seasonal snow cover at a Swiss Alpine site by 50 days/yr, and with a 50% increase in precipitation by 30 days/yr.

Adaptation

Adaptation potential of European countries is relatively high, because of high gross domestic product and stable growth, educated and stable population (with possibility to move across the region) and well developed political, institutional, and technological support systems (Kundzewicz and Parry, 2001). Adaptation to weather extremes allows curbing the exposure, the adverse impacts, and the vulnerability. A special European Union (EU) Solidarity Fund (Hochrainer et al., 2010) has been established to assist recovery after major natural disasters, and national and EU adaptation programmes are being implemented in several countries as well as in the (CEC, 2009). However, some groups of people – economically disadvantaged, elderly, living alone or having pre-existing disease, are particularly vulnerable. The natural ecosystems in Europe that are most vulnerable to climate change and climate extremes are located in the Arctic, in mountain regions, in coastal zones (especially the Baltic wetlands) and in various parts of the Mediterranean, where ecosystems are already affected by ongoing warming and decreasing precipitation (Alcamo et al., 2007).

Much work is being done in Europe to improve flood preparedness, including EU Floods Directive and activities of river basin commissions. Due to the large uncertainty of climate projections, it is currently not possible to devise a rigorous, scientifically-sound, procedure for redefining design floods (e.g. 100-year flood) under strong non-stationarity of the changing climate and land use. For the time being it is recommended to adjust design floods using a “climate change safety factor” approach (Kundzewicz et al., 2010).

Adaptation makes it possible to enhance beneficial effects of climate change (e.g. by introducing longer-cycle varieties where wetter conditions are expected in the future warmer climate in the North of Europe) as well as to reduce the negative effects (e.g. by advancing sowing time for crops grown in the Mediterranean basin), cf. Moriondo et al. (2010).

Promising adaptation options of forestry to gale winds in Europe were found (Schelhaas et al., 2009) to limit the increase in exposure and vulnerability, e.g. by increasing the harvest levels that curb the current build-up of growing stock and reduction of the share of old and vulnerable stands.

[INSERT TABLE 4-14 HERE

Table 4-14: Summary of climate extremes in Europe – hazard, exposure, vulnerability, and impacts

4.5.5. Latin America

Extreme droughts and the vulnerability of the Amazon forest

In the short span of 4 years, the Amazon basin experienced one of its most severe droughts in 2005 (Marengo et al. 2008a, Zheng et al. 2008) and a very large, record breaking discharge in 2009 (Climanalise, 2009). The 2005 drought was atypical because it affected mostly the western and southwestern Amazon, as opposed to the more typical El Niño-related droughts which affect central, northern and eastern Amazon, such as the severe drought in northern Amazon in early 2010 (Climanalise, 2010). It is uncertain what the ecological impacts of the droughts are since satellite-based analyses of productivity (Saleska et al, 2007; Huete et al., 2006) show increased productivity in the affected areas during droughts, while other study based on in in-situ forest inventories observed loss of productivity and increased tree mortality and carbon loss (Phillips et al., 2009) during droughts and subsequently. By and large, droughts in the Amazon are strongly linked to enormous increases in forest fires (Aragão et al., 2007, Cochrane and Laurance, 2008; Mlahi et al., 2008).

A number of studies (reviewed extensively in Nobre and Borma, 2009) attempted to determine quantitatively ‘tipping points’ for the Amazon forest in terms of climate change due to global warming or to deforestation. Current figures indicate that there could be a partial collapse of the Amazon forest (also termed ‘savannization’ because the new climate would be typical of tropical savannas) for global warming exceeding 3.5 to 4 C (Salazar et al., 2007, Betts et al., 2008) or for the total deforested area surpassing 40% of the total forest area (Sampaio et al., 2007). If the frequency of droughts in the Amazon increase, as projected by some studies (Cox et al., 2008; Marengo et al., 2009), coupled to increase of forest fires (Nepstad et al., 2004, Cardoso et al., 2008, Nepstad et al., 2008), the Amazon forest will become much more vulnerable (Nobre and Borma, 2009). Long-term rainfall-exclusion experiments for central (Nepstad et al., 2007 and Brando et al., 2008) and northeastern Amazon (Fischer et al., 2007) showed large tree mortality.

Extreme rainfall and natural disasters: Examples from Venezuela and Southern Brazil
Extreme rainfall episodes have caused natural disasters of great proportion in parts of Latin America, causing hundreds to thousands of fatalities in mud/land slides, where the disasters of December 1999 (Lyon, 2003) and February 2005 in Venezuela and the one in November 2008 in southern Brazil (Silva Dias et al., 2009) are typical illustrations of the serious impacts of such incidents. Projections of rainfall extremes for the future, although highly uncertain at present, point out for more intense rainfall episodes due to global warming (Marengo et al., 2009). Extreme rainfall anomalies over South America are linked to large-scale SST anomalies (Halylock et al. 2006). When the North Tropical Atlantic (NTA) and the Equatorial Pacific (Niño 3 region) anomalies are of opposite signs and the first one is positive while the second one is negative, the rainfall response is stronger in the northern coast of Venezuela as well as in the Pacific coast of Central America during the Nov-Feb period, which partly explains the extreme rainfall of those two episodes. In the future, that configuration in SSTs leading dry season rainfall extremes may hold and even increase for SRES A2 experiments for the middle part of the century (Guenni et al., 2010). So far, the response to those devastating episodes in Venezuela has been to develop an early warning system for rainfall and mudslide risk and a preparedness program for people exposed to risk (Wieczorek et al., 2001).

A generalized increase of rainfall over SE South America over the last 30 years, attributed mostly to the positive phase of the PDO and more frequent El Niño episodes, is well documented (Barros et al., 2008. Grim and Tedeschi, 2009, among many others). If that is the driving mechanism of rainfall increase, it may decrease in the present and future decades since the PDO may have changed phase (e.g., Vera and Silverstrini, 2008). However, that region has been simultaneously experienced warming and the increase of frequency of intense rainfall episodes (> 100 mm/48 hours) (Camiloni et al., 2005) in that broad region can be attributed in part to the warming (Marengo et al., 2008b). That kind of intense rainfall is projected to increase in the future (Marengo et al. 2009). In particular, the Itajaí-Açu river basin, in Santa Catarina, southern Brazil, is naturally very prone to devastating floods, normally associated to El Niño-related abundant rainfall (Silva Dias et al., 2009). In November 2008, that river valley experienced its most severe flood in recorded history, with 5-day rainfall records exceeding 500 mm along the basin, claiming over 130 lives, mostly due to mud slides in hills on the edge of the floodplain (Silva Dias et al., 2009).

The response to historical floods in the Itajaí-Açu valley illustrates how complex social mechanisms to seek adaptation to climate extremes can be. One response to the extensive 1983 floods in that valley was to implement a hydrological early warning system for the flood plain. To reduce exposition to risk, gradually inhabitants living in the floodplain moved to higher ground, particularly occupying steep forested hills on the edges of the floodplain, and deforesting them in the process of occupation. The majority of casualties in November 2008 were caused by mudslides on the those hills (Fundação BUNGE, 2009). In sum, to escape from one hazard (floods), the population became vulnerable to other risk (mudslides) (Silva Dias et al., 2009).

4.5.6. North America

[Pending]

4.5.7. Oceania

The region of Oceania consists of Australia and New Zealand and several Small Island States that are tackled in Section 4.5.10.

Introduction
Extreme events have severe impacts in both Australia and New Zealand. In Australia, weather-related events cause around 87% of economic damage due to natural disasters (storms, floods, cyclones, earthquakes, fires and landslides), cf. BTE (2001). In New Zealand, floods and droughts are the most costly climate disasters (Hennessy et al., 2007).

The climate of the 21st century in the Oceania region is virtually certain to be warmer, with changes in extreme events. Heat waves and fires, floods, landslides, droughts and storm surges are projected to increase in intensity and frequency. Rain events are likely to become more intense, leading to greater storm runoff, but with lower river levels between events. Risks to major infrastructure are likely to increase i.e. design criteria for extreme events - to be exceeded more frequently. Risks include failure of floodplain protection and urban drainage/sewerage, increased storm and fire damage, and more heat waves, causing more deaths and more blackouts. Economic damage from extreme weather is very likely to increase and provide major challenges for adaptation (Hennessy et al., 2007).

The El Niño-Southern Oscillation (ENSO) is a strong regional driver of climate variability. In Australia, El Niño brings warmer and drier conditions to eastern and south-western regions (Power et al., 1998). In New Zealand, El Niño brings drier conditions in the north-east and wetter conditions in the south-west (Gordon, 1986; Mullan, 1995). The converse occurs during La Niña, in both Australia and New Zealand.

Temperature extremes

Trends in the frequency and intensity of most extreme temperature are rising faster than the means (Alexander et al., 2007).

In Australia, from 1910 to 2004, the average maximum temperature rose 0.6°C and the minimum temperature rose 1.2°C (Nicholls and Collins, 2006). From 1957 to 2004, an increase in hot days (above 35°C) of 0.10 days/yr was observed in the Australian average, an increase in hot nights (above 20°C) of 0.18 nights/yr, a decrease in cold days (below 15°C) of 0.14 days/yr and a decrease in cold nights (below 5°C) of 0.15 nights/yr (Nicholls and Collins, 2006).

During the Eastern Australian heat wave, in February 2004, temperatures reached 48.5°C in western New South Wales. About two-thirds of continental Australia recorded maximum temperatures over 39°C. The Queensland ambulance service recorded a 53% increase in ambulance call-outs (Steffen et al., 2006).

An increase in heat-related deaths is projected in the warming region (Hennessy et al., 2007). Assuming no planned adaptation, the number of deaths is likely to rise from 1,115/yr at present in Adelaide, Melbourne, Perth, Sydney and Brisbane to 2,300 to 2,500/yr by 2020, and 4,300 to 6,300/yr by 2050, for all SRES scenarios, including demographic change (McMichael et al., 2003). In Auckland and Christchurch, a total of 14 heat-related deaths occur per year in people aged over 65, but this is likely to rise to 28, 51 and 88 deaths for warmings of 1, 2 and 3°C, respectively (McMichael et al., 2003). Ageing of the society is likely to amplify these figures. By 2100, the Australian annual death rate in people aged over 65 is estimated to increase from a 1999 baseline of 82 per 100,000 to 131-246 per 100,000, for the SRES B2 and A2 scenarios and the 450 ppm stabilisation scenario (Woodruff et al., 2005). Australian temperate cities are likely to experience higher heat-related deaths than tropical cities (McMichael et al., 2003).

Droughts

Droughts have become more severe because temperatures are higher for a given rainfall deficiency (Nicholls, 2004). In Australia, the damages due to droughts of 1982-1983, 1991-1995 and 2002-2003 were US$2.3 billion, US$3.8 billion and US$7.6 billion, respectively (Hennessy et al., 2007).

New Zealand has a high level of economic dependence on agriculture and drought in particular can cause significant disruption. The 1997-98 El Niño resulted in severe drought conditions across large areas of New Zealand with losses estimated at NZ$750 million (2006 values) or 0.9 per cent of GDP (OCDESC, 2007: 82). Drought conditions also have a serious impact on electricity production in New Zealand where 60 per cent of supply is from hydroelectricity and low precipitation periods result in increased use of fossil fuel for electricity generation, a mal-adaptation to climate change. Auckland, New Zealand's largest city suffered from significant water shortages in the early nineteen-nineties, but has since established a pipeline to the Waikato River to guarantee supply.

Droughts impact on water security in the Murray-Darling Basin in Australia, accounting for most of irrigated crops and pastures in the country. Annual streamflow in the Basin is likely to fall 10-25% by 2050 and 16-48% by 2100 (Hennessy et al., 2007).

Climate change is likely to change land use in southern Australia, with cropping becoming non-viable at the dry margins if rainfall is reduced substantially, even though yield increases from elevated CO_2 partly offset this effect (Sinclair et al., 2000; Luo et al., 2003).

Wildfire

Wildfires around Canberra in January 2003 caused US$261 million damage (Lavorel and Steffen, 2004), with about 500 houses destroyed, four people killed and hundreds injured. Three of the city's four dams were contaminated for several months by sediment-laden runoff (Hennessy et al., 2007).

An increase in fire danger in Australia is associated with a reduced interval between fires, increased fire intensity, a decrease in fire extinguishments and faster fire spread (Hennessy et al., 2007). In south-east Australia, the frequency of very high and extreme fire danger days is likely to rise 4-25% by 2020 and 15-70% by 2050 (Hennessy et al., 2006). By the 2080s, 10-50% more days with very high and extreme fire danger are likely in eastern areas of New Zealand, the Bay of Plenty, Wellington and Nelson regions (Pearce et al., 2005), with increases of up to 60% in some western areas. In both Australia and New Zealand, the fire season length is likely to be extended, with the window of opportunity for controlled burning shifting toward winter (Hennessy et al., 2007).

Intense precipitation and floods

From 1950 to 2005, extreme daily rainfall has increased in north-western and central Australia and over the western tablelands of New South Wales (NSW), but has decreased in the south-east, south-west and central east coast (Gallant et al., 2007).

Floods are New Zealand's most frequently experienced and expensive hazard (OCDESC, 2007) affecting both agricultural and urban areas. Being long and narrow New Zealand is characterised by small river catchments and accordingly shorter flood warning times.

Increase in precipitation intensity is likely to cause greater erosion of land surfaces, more landslides, and a decrease in the protection afforded by levees (Hennessy et al., 2007). Assuming the current levee configuration, the proportion of the Westport town (New Zealand) inundated by a 1-in-50 year event is currently 4.3%, but rises to 13 to 30% by 2030, and 30 to 80% by 2080 (Gray et al., 2005). Peak flow increases 4% by 2030 and 40% by 2080.

Storm surges

Over 80% of the Australian population lives in the coastal zone, with significant recent non-metropolitan population growth (Harvey and Caton, 2003). About 711,000 addresses (from the National Geo-coded Address File) are within 3 km of the coast and less than 6 m above sea level, with more than 60% located in Queensland and NSW (Chen and McAneney, 2006). These are potentially at risk from long-term sea-level rise and large storm surges (Hennessy et al., 2007). The area of Cairns at risk of inundation by a 1-in-100 year storm surge is likely to more than double by 2050 (McInnes et al., 2003).

Tropical cyclones

There is no trend in the frequency of tropical cyclones in the Australian region from 1981 to 2003, but there has been an increase in intense systems (very low central pressure) (Kuleshov, 2003; Hennessy, 2004).

Adaptation

Australia and New Zealand have a long history of flood management, though early attempts were mostly structural. Since the mid-twentieth century legislation has existed in New Zealand to enable a full range of responses including modifying the environment, modifying flood loss susceptibility and modifying the loss burden. Until the 1990s, however, most effort went into the former, as there were significant government subsidies for local catchment authorities to build stopbanks and other protective works. On the other hand non-structural measures tended to be over looked at the local planning level leading to intensive development in 'protected areas' and increased vulnerability to supra-design events (Ericksen, 1986). Economic restructuring in the second half of the 1980s resulted in the removal of subsidies, local government reform resulted in the merging of catchment management with other regional planning activities and the introduction of The Resource Management Act (1991) which had

sustainable management as its cornerstone, and which replaced both catchment oriented and planning legislation, saw significant change towards a cooperative regime for hazard management (Dixen et al., 1997).
Other hazard related legislation in New Zealand includes the Building Act 2004 and the Civil Defence Emergency management Act 2002. For agricultural disasters, particularly drought, farmers are eligible for Adverse Events recovery assistance administered by the Ministry of Agriculture Forestry and to social welfare services (Ministry of Social Development) where their income is severely reduced. Where farm it is considered that farms are unsustainable 'new start' grants are made available to assist farmers to leave the industry (Ministry of Agriculture and Forestry, 2010).

[INSERT TABLE 4-15 HERE:
Table 4-15. Climate extremes, vulnerability, and impact.]

4.5.8. Open Oceans

The ocean's huge mass in comparison to the atmosphere gives it a driving role in global heat budgets and chemical budgets. However, a very high level of uncertainty confounds predictions of extreme ocean events related to climatic changes (Keller et al., 2007). Possible extreme events are likely to be triggered by (1) warming of the surface ocean, with a major cascade of physical effects, (2) ocean acidification induced by increases in atmospheric carbon dioxide, and (3) reduction in oxygen concentration in the ocean due to a temperature-driven change in gas solubility and physical impacts from (1). All have potentially non-linear multiplicative impacts on biodiversity and ecosystem function, and each may increase the vulnerability of ocean systems, triggering an extreme event such as a mass extinction.

Surface warming of the oceans can itself directly impact biodiversity by slowing or preventing growth in temperature-sensitive species. One of the most well-known biological impacts of warming is coral bleaching, but ocean acidification also plays a role in lowering coral growth rates (Bongaerts et al., 2010). Direct impact of warming on other marine plants and animals, including the plankton, is likely to be important and will change how open ocean ecosystems operate, potentially favouring bacterial plankton over larger organisms (Legendre and Rivkin, 2008). Fish populations have been seen to be vulnerable to climate change both through direct impacts of temperature changes and acidity, and also via the altered ocean circulation (Johnson, 2010). These changes are likely to impact the overall catch potential in fisheries worldwide (Cheung et al., 2008).

A secondary impact of warming is the potential reduction in oxygen concentrations due to decline in the chemical capacity of seawater to retain dissolved oxygen at higher temperatures (Whitney et al., 2007). It has been predicted that deoxygenation will occur at 1 – 7% over the next century via this mechanism alone, continuing for 1000 years or more into the future (Keeling et al., 2010). An important impact may be an expansion of already existing oxygen minimum zones, especially in tropical oceans, which can kill animals at concentrations ranging from 40 to 200 µmol L^{-1} oxygen, depending on the species (see Figure 4-15; Vaquer-Sunyer and Duarte, 2008).

[INSERT FIGURE 4-15 HERE:
Figure 4-15: Median lethal oxygen concentration (μmol L^{-1}. Median lethal oxygen concentration (LC_{50}, in μmol L^{-1}) amoung four different taxa. The box runs from the lower (Q_1, 25%) to the upper (Q_3, 75%) quartile and also includes the median (*thick vertial line*). The range of data points not considered outliers is defined as 1.5 times the difference betweeen the quartiles (Q_3-Q_1), also known as interquartile range (IQR). The whiskers show the location of the lowest adn highest datum within this range, i.e., 1.5 * IQR. Shaded diamonds are outliers as per this definition. Redrawn after Vaquer-Sunyer & Duarte (2008). Copyright (2008) National Academy of Sciences, U.S.A.]

However, some of the greatest impacts of warming are likely to be generated by the changes in marine circulation induced by warming that could act to isolate surface waters from deep waters, a mechanism known as "stratification", which involves heat-induced layering of the surface ocean, inhibiting deep mixing. Among other impacts, this exacerbates the deoxygenation problem many-fold by preventing ventilation of deep waters to the surface, where they can re-oxygenate in contact with air. This then physically limits the re-oxygenation of the ocean interior (Keeling et al., 2010). In addition, almost all climate models predict an increase in evaporation in the tropics and increased precipitation in high latitudes, which would increase stratification by the input of low-density fresh water at the ocean surface (Orr et al., 2005).

This limitation of exchange seems to override the potentially positive impact on oxygen concentrations driven by a reduction in surface productivity in more permanently stratified waters (Keeling et al., 2010): A reduction in mixing reduces the regular delivery of deep nutrients to the surface of the ocean needed to fertilize light-driven photosynthesis by the plant plankton ("phytoplankton", that release oxygen). This reduction in nutrient supply has another cascade of impacts. Low nutrient conditions are likely to support species of phytoplankton with lower nutrient requirements that are of poorer nutritional value to their crustacean "zooplankton" predators, thus changing the structure and function of entire aquatic food webs (van de Waal et al., 2010). This sort of impact has been documented as a reduction in krill populations and an increase in jellies such as *salps* in the Southern Ocean (Atkinson et al., 2004).

Climate changes affect the temperature and salinity of ocean and global termohaline circulation, and also sea ice which influences communication between oceanic and atmospheric processes (Barber *et al*., 2008). One of the most profound and potentially rapid changes in circulation predicted by climate models is the possible failure of the Meridional Overturning Circulation (MOC) in the North Atlantic. The MOC is the northward flow of water in the surface Atlantic Ocean which brings warm water from the tropics towards the Arctic. The water cools progressively as it moves north due to heat-loss to the atmosphere, eventually cooling to such a density that it sinks to the deep ocean and tracks southward again, along the sea floor. The MOC is one of the oceans' most important vertical mixing regions, where large amounts of surface gases (including CO_2), and plankton (in this context, stored carbon), are carried deep into the ocean interior. Once there, these materials are essentially stored for the period of a whole ocean overturn, that is, about 1000 years. Many models predict a weakening or collapse of the MOC in response to climate change, due both to surface warming and to an increase in freshwater influx from melting polar sea-ice (Keller et al., 2010). Enormous effort has gone into reducing uncertainties associated with these predictions because of the potentially catastrophic environmental and economic impact associated with an MOC failure (Brennan et al., 2008), since an MOC would radically alter current climate patterns. Some models predict a "fast feedback" involving increased cloud cover and significant surface cooling throughout Western Europe (Laurian et al., 2009). Changes in the MOC in geologic history were associated with large and abrupt climatic changes in the North Atlantic region, including collapse of plankton stocks and significant reductions in ocean production (Schmittner, 2005).

Finally, the dissolution of increasing concentrations of carbon dioxide into the ocean from the atmosphere perturbs the carbon-dioxide - carbonate equilibrium such that the ocean becomes more acidic and calcium concentrations are reduced. Calcification of marine organisms is one of the key processes likely to be disrupted by acidification, of central importance because of its involvement in the formation of hard structures (coral skeletons, invertebrate shells, carapaces of larval fish). The primary open-ocean impacts will occur initially in high latitude regions such as the Southern Ocean, where significant reductions in calcium availability are likely to occur by 2050 (Orr et al., 2005), but will move progressively into lower latitudes. This, in combination with warming, is likely to pose a major threat to coral reefs (Jury et al., 2010). But some of the major impacts may be seen primarily in high latitudes – especially vulnerable, for example, are shelled organisms called *pteropods*. These are important high latitude zooplankton feeding major fish groups including salmon and herring, as well as baleen whales, and also perform a carbon storage function, carrying embedded carbon from the surface to the deep ocean via sedimentation of their shells (Orr et al., 2005).

In concert, it is expected that the impact of several concurrent impacts (temperature, stratification, acidity) increases the probability for extreme events in the ocean.

Changes in open oceans are particularly strong in polar regions (cf. 4.5.9). Spectacular reduction of the total Arctic sea ice area, based on satellite data, has been detected (Serreze et al., 2007). The maximum value in the period 1979-2009 (7.88 million km^2) was observed in September (seasonal minimum) 1996, and the minimum (4.3 million km^2, i.e. nearly twice less) - in September 2007. In the period 1990-2005, the perennial ice thickness was reduced, on the average, by 110 cm throughout the Arctic basin, as compared with its average thickness of about 3 m (Nagurnyi, 2009).

[INSERT FIGURE 4-16 HERE:
Figure 4-16: Ice covered area (S) in Arctic in September (million square kilometers). Data from [NSIDC ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/Oct/N_9_area.txt.]

Ice cover does not allow navigation of the ships. Navigation in the Arctic Ocean is only possible during the time interval when northern coasts of Eurasia and North America do not have ice cover. During periods of low ice concentration, ships are navigated towards ice-free passages, away from multi-year ice (that has accumulated over several years). Regional warming provides favourable conditions for the sea transport going through the Northern Sea Route along the Eurasian coasts and through the Northwestern Passage in the north of Canada and along Alaska (Impact of Warming Arctic, 2004). In September 2007, when the Arctic Sea ice area was extremely low, ice disappeared almost completely in northern passages of the North America and Northwest Passage was opened up. In Russia, this enabled service of ports of the Arctic region and remote Northern regions (import of fuel, equipment, food, timber, and export f timber, oil, and gas). However, owing to deglaciation in Greenland, New Land and Northern Land, the number of icebergs is suggested to increase (Strategic Prediction, 2005; Materials to the Strategic Prediction, 2005; Assessment Report, 2008).

The seasonal sea ice cycle affects also biological habitats. Such species of Arctic mammals as: polar bears, seals, and walruses, depend on the sea ice for their habitat; hunting, feeding, and breeding on the ice. Declining sea ice is likely to decrease polar bear numbers (Stirling and Parkinson, 2006).

Marine fisheries productivity is affected by changes in ocean conditions resulting from climate change. Food web structure and species distribution change. Marine fish and invertebrates tend to shift their distributions toward higher latitudes and deeper waters in response to climate change. Relative abundance of species may also change as some habitats become less appropriate for them (Redistribution of Fish Catch by Climate Change, 2009). Climate change may lead to large-scale redistribution of global fish catch potential, with a 30–70 percent increase in high latitude regions, e.g. the North Atlantic, North Pacific and poleward (Redistribution of Fish Catch by Climate Change, 2009).

It is assessed that 30 percent of the phytoplankton increase between 2006 and 2007 was due to large new areas of open water exposed due to extensive melting of sea ice. The other 70 percent of the increase could be attributed to a longer growing season, which in some Arctic regions was extended in 2007 by as much as 100 days, compared to 2006. Whales, seals, marine birds, zooplankton, and other marine animals all depend either directly or indirectly on phytoplankton for food.

4.5.9. Polar Region

Introduction

The Polar region consists of the Arctic, around the North Pole and the Antarctic, around the South Pole. Climate change in the Polar region is noticeable. Slow climate changes in the Polar regions can lead to extreme impacts. The Arctic region consists of a vast north treeless permafrost territory (north of Europe, Asia and North America, and several islands (including Greenland).

In the last century, air temperature in the Arctic region has risen twice as fast as the global temperature. In the Arctic region, the warming first leads to changes in cryosphere. Observational data are limited, but precise measurements in boreholes indicate that permafrost temperatures in the Arctic rose markedly during the last 50 years (Romanovsky et al., 2002), with rapid warming in Alaska (Hinzman et al., 2005), Canada (Beilman et al 2001) and Siberia (Pavlov and Moskalenko, 2002, Sherstyukov, 2009) and seasonal thaw depth (permafrost degradation) was observed. Sea ice extent in the Arctic Ocean has shrunk, improving navigation in the Arctic Region (cf. 5.4.8). Among other changes observed are: increase of inter-annual variability and extremeness of climate parameters and earlier onset of springs (temperature zero crossover).

Population density in the Polar region is low, so that impacts of climate change, and extremes, are not equally noticeable everywhere. The territory of Russian Arctic is more populated than other Polar regions. On this territory, impacts of climate change are most noticeable and affect human activities.

The positive impact of climate change is the reduction in heating season almost throughout the Arctic region. Apart from its duration, an important index is the heat deficit (heating degree-days) which needs to be compensated to maintain comfort temperature (Sherstyukov, 2007).

Warming cryosphere

For several key Arctic systems, notably Arctic sea ice and the Greenland Ice Sheet, recently observed changes are happening at rates significantly faster than predicted in previous expert assessments, notably IPCC AR4. While this primarily reflects the current limits of scientific understanding of the Arctic it also raises questions about the range of climate impact predictions that guide mitigation and adaptation (Stroeve et al., 2007).

Analysis of extent of melt of the Greenland ice sheet using passive microwave satellite data has shown a dramatic increasing melt trend since 1979 which appeared to be interrupted only in 1992 by the eruption of Mt. Pinatubo. Extreme melt years were 1991, 1995, and again 2002 (Abdalati and Steffen, 2001).

Recent changes in the Greenland ice sheet have, however, been complex. The colder interior has thickened, most probably as a result of recently high precipitation rates, while the coastal zone has been thinning. There is a growing body of evidence for accelerating coastal thinning, a response to recent increases in summer melt, and acceleration of many coastal glaciers suggest that thinning is now dominating the mass balance of the entire ice sheet. Using satellite radar interferometry observations of Greenland, Rignot and Kanagaratnam (2006) detected widespread glacier acceleration below 66° north between 1996 and 2000, which rapidly expanded to 70° north in 2005. Accelerated ice discharge in the west and particularly in the east doubled the ice sheet mass deficit in the last decade from 90 to 220 cubic kilometers per year. As more glaciers accelerate farther north, the contribution of Greenland to sea-level rise will continue to increase.

Climate warming leads to permafrost degradation, the 40-80-cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost (Sherstyukov, 2009).

Warming and thawing of the frozen ground in the Arctic region results in considerable mobilisation of greenhouse gases (Anisimov, 2007). The end-products of decomposition of the ancient organic substance are CO_2 (in aerobic conditions) and CH_4 (in anaerobic conditions). According to existing estimations, only the top hundred-metre layer of a frozen ground of the Arctic region contains about 10 thousand Gt of carbon (Semiletov, 1995, 1995, Zimov et al., 1997). Emissions of CO_2 from frozen ground and methane from gas-hydrates, can lead to essential increase of greenhouse gas concentration in the atmosphere and increase of global climate changes (Shakhova et al., 2005).

As frozen ground thaws, many existing buildings, roads, pipelines, airports, and industrial facilities are destabilized. From 1990 to 1999 the number of buildings which had various sorts of damage has increased in comparison with previous decade by 42 % - 90 % in the north of Western Siberia (Anisimov and Belolutsky, 2002; Weller and Lange, 1999).

An apartment building collapsed following melting permafrost in the upper part of the Kolyma River Basin, and over 300 buildings were severely damaged in Yakutsk as a result of retreating permafrost. More than half of buildings in Pevek, Anderm, Magadan, and Vorkuta have also been damaged (Anisimov, Belolutskaya, 2002; Anisimov, Lavrov, 2004). Approximately 250 buildings in Norilsk industrial district had significant damage caused by deteriorating permafrost and approximately 40 apartment buildings have been torn down or slated for demolition (Grebenets, 2006).

Changes in permafrost damage the foundations of buildings and disrupt the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10-12% in 20-25 years, with permafrost borders moving 150-200 km northeast (Anisimov *et al.*, 2004).

In polar region, in the conditions of impassability, frozen rivers are often used as transport ways. In the conditions of climate warming, rivers freeze later and melt earlier than before. Duration of operation of transport ways to the Far North of Russia decreases with increase of air temperature in winter and spring (Mirvis, 1999). Work in tundra has become much more difficult given impediments of passing through the melted tundra.

Although seasonal snow cover on land is highly variable, it has important effects on the processes and local climate, primarily through its insulating properties and high albedo. In Eurasia, and to a lesser extent North America, there has been a persistent 5-6 day/decade increase in the duration of snow-free conditions over the past three decades (Dye, 2002). The reduction of snow residence time occurs primarily in spring. Projections from different climate models generally agree that these changes will continue. Likely impacts include increases in near-surface ground temperature, changes in the timing of spring melt-water pulses, and enhanced transportation and agricultural opportunities (Anisimov et al., 2005).

In the north of Eurasia, duration of snow cover has decreased in last decades (Shmakin, 2010) and accumulation of snow in spring is capable to thaw intensively and to cause flooding. The annual number of days with sharp warming has increased in the north of Eurasia. In such days there is a sharp thawing of snow (Shmakin, 2010).

The warming in the Arctic leads to a shift of vegetation zones, bringing wide-ranging impacts and changes in species diversity, range, and distribution. In Alaska, over the last 50 years the confines of the forest zone have shifted to the North by 10 km displacing tundra zone (Tape et al., 2006; Sturm et al., 2001). In the mountain regions of North Sweden forests have shifted upwards by 60 m over a hundred years (Truong, Palm, 2006). As warming in the Russian Arctic degrades permafrost, vast territories of tundra may be replaced by taiga.

Floods

From mid 1960s to the beginning of 1990s, winter runoff of the largest rivers of Siberia (Yenisei, Lena, Ob; the total runoff of these three rivers makes approximately 70 % of the global river runoff into the Arctic Ocean) has increased by 165 km^3, i.e. about annual production of ground waters on a shelf of Pacific sector of Arctic regions (Savelieva et al., 2004).

Changes in freshwater inflow to the system of Arctic Ocean - Northern Atlantic may affect the performance of the termohaline circulation. The processes occurring on the scale of the Arctic region, are capable to change the climate system at the planetary scale.

Rivers in Arctic Russia experience floods, but their frequency, stage and incidence are different in different parts of the Region, depending on flood formation conditions. Floods on the Sibierian rivers can be produced by a high wave of the spring flood and by rare rain or snow-rain flood, as well as by ice jams, hanging dams and combinations of factors.

Maximum river discharge was found to decrease from the mid-20th century to the early 1980s in to Western Siberia and the Far East, except for the Yenisei and the Lena rivers that exhibit positive trends. However, in the last three decades, maximum streamflow values began to increase over the most of the Arctic Russia (Semyonov and Korshunov, 2006), cf. Figure 4-17.

[INSERT FIGURE 4-17 HERE:
Figure 4-17: Annual change in the number of hazardous floods on rivers of Eastern Siberia, Western Siberia, and the Far East 1991-2006.

Snowmelt and rain floods on the rivers in the Russian Arctic continue to be the most frequent cause of hazardous floods (85% of all hazardous floods in the past 15 years). Hazardous floods produced by ice jams and wind tides make up 10% and 5% of the total number of hazardous floods, respectively. In the early 21st century, the probability of catastrophic wind tide-related floods (Pomeranets, 2005) and ice jam-related floods increased. The damage from floods depends not only on their level, but also on the duration of exposure. On average, a flood lasts 5-10 days, but sometimes high water marks are recorded to persist longer, e.g. for 20 days or more (Semyonov and Korshunov, 2006), in Altai, Transbaikalia and some areas of the Maritime Territory and Sakhalin with monsoon climate.

An increased number of damage-causing floods was recorded in Western Siberia, 86 (of which 31 in the Altai Territory and 14 in the Kemerovo Region), Eastern Siberia, 67 (28 in the Krasnoyarsk Territory and 16 in the Chita Region), and in the Northern area, 10 out of 17 floods occurred in the Arkhangelsk Region. (Assessment Report, 2008).

Droughts

Polar regions feature insecure agriculture and, among Polar regions, grain is produced mainly on the territory of Russia. Droughts have considerable and negative impact on the crop yield. In some regions of Siberia, climate became more arid, leading to the decrease in productivity of agriculture (Sirotenko et al., 2007). A decrease in productivity of ecosystems was noted in central and northeastern parts of European Russia, in the south of Eastern Siberia and in the Far East (Sirotenko, Abashina, 2008). Modelling of forest fires in Siberia shows that the warming may result in the increase of risk of severe forest fires.

Coastal erosion

Coastal erosion along a 40-mile stretch of Alaska's Beaufort Sea doubled between 2002 and 2007. It is linked to the declining sea ice extent, increasing summertime sea-surface temperature, rising sea level, and increases in storm power and corresponding wave action. The recent trends toward warming sea-surface temperatures and rising sea-level may act to weaken the permafrost-dominated coastline by helping more quickly thaw ice-rich coastal bluffs and may potentially explain the disproportionate increase in erosion along ice-rich coastal bluffs relative to ice-poor coastal bluffs. Any increases in already rapid rates of coastal retreat will have further ramifications on Arctic landscapes - including losses in freshwater and terrestrial wildlife habitats, in subsistence grounds for local communities, and in disappearing cultural sites, as well as adversely impacting coastal villages and towns. In addition, oil test wells are threatened (Jones et al., 2009).

Coastal erosion is a significant problem in the Arctic. The Arctic coastlines are highly variable and their dynamics are a function of environmental forcing (wind, waves, sea-level changes, sea-ice, etc.), geology, permafrost and other elements (Rachold et al., 2005). Under global warming scenarios, the risk of entire communities disappearing due to coastal erosion is greatly increased. The cost to move an entire village or town could devastate the local economy. Therefore, a better understanding of global warming effects and atmospheric forcing on the coast is essential.

Permafrost degradation along the coast of the Kara Sea may lead to intensified coastal erosion, which moves the coastline back by 2-4 meters per year (Anisimov, Lavrov, 2004). This coastline retreat poses considerable risks for coastal population centres in Yamal and Taymyr and on other littoral lowland areas.

Climate refugees may emerge if climate change significantly damages housing. There have already been climate refugees in Arctic territories of the United States (Shishmaref) and Canada (Tuktyaktuk). Coastal erosion has also become a problem for residents of Inupiat and on the island of Sarichev.

4.5.10. Small Island States

Introduction

Small island states, on the Pacific, Indian and Atlantic oceans, are regularly identified as being among the most vulnerable to climate change and climate-related natural disasters (e.g. Hyogo Declaration; Barbados Declaration, UNFCCC). In the light of current experience and model-based projections, small island states, with high vulnerability and low adaptive capacity, have legitimate concerns about their future (Mimura et al., 2007). Changes to climate means or variability may lead to extreme impact. Smallness renders island countries at risk of very high proportionate losses when impacted by disaster (Lewis, 1979; Pelling and Uitto, 2001).

Climate-driven sea-level rise could lead to a reduction in island size, particularly in the Pacific. Island infrastructure tends to predominate in coastal locations, e.g. in the Caribbean and Pacific islands, more than 50% of the population live within 1.5 km of the shore. Nearly all international airports, roads and capital cities in the small islands of the

Indian and Pacific Oceans and the Caribbean are sited along the coast, or on tiny coral islands. Sea-level rise will exacerbate inundation, erosion and other coastal hazards, threaten vital infrastructure, settlements and facilities, and thus compromise the socio-economic well-being of island communities and states. There is also strong evidence that under climate change, water resources in small island states, that are especially vulnerable to future changes and distribution of rainfall, will be seriously compromised. For example, many islands in the Caribbean are likely to experience increased water stress as a result of climate change (Mimura et al., 2007).

Since the early 1950s, by which time the quality of disaster monitoring and reporting improved in the Pacific Islands Region, there has been a general increasing trend in the number of disasters reported annually (Hay and Mimura, 2010).

Demography and Geography

Pacific Island Countries and Territories (PICTs) exhibit considerable demographic variety. The population of the region in 2009 stood at 9,677,000. This is dominated by Melanesia with almost 8.5 million people of which over 6.5 million lived in Papua New Guinea. At the other end of the scale there are some very small countries and territories with populations below 2,000 people (Tokelau and Niue). Population densities vary, but tend to be lowest in the most populous Melanesian countries, and highest in the small atolls. Population growth rates also vary but tend to be higher in Melanesia. The projected regional population for 2050 is 18.2 million (Source of data: SPC, 2009).

PICTs have a variety of characteristics rendering generalization difficult (see Table 4-16). There are four main types of island ranging from large inter-plate boundary islands formed by subduction and found in the south west Pacific Ocean which may be compared to the Oceanic (or intra-plate) islands which were, or are being, formed over ‘hot spots’ in the earth’s mantle. Oceanic islands range from volcanic high islands, some of which are still being formed and some of which are heavily eroded with step slopes and barrier reefs, to atolls which consist of coral built on submerging former volcanic high islands, through raised limestone islands, former atolls stranded above contemporary sea-levels. Each island type has specific characteristics in relation to disaster risk reduction. For example, atolls are particularly vulnerable to tropical cyclones, where storm surges can completely inundate them and there is no high ground to which people may escape. In contrast the inter-plate islands are characterized by large river systems and fertile flood plains in addition to deltas, both of which tend to be heavily populated. Fatalities in most of the worst climate related disasters in the region have been mostly from river flooding. Raised atolls are often saved from the storm surge effects of tropical cyclones, but during Cyclone Heta which struck Niue 2004, the 20m cliffs were unable to provide protection.

[INSERT TABLE 4-16 HERE:
Table 4-16: Pacific Island type and exposure to risks arising from climate change.]

Exposure

Drought is a hazard of considerable importance in PICTs. Atolls, in particular, have very limited water resources being dependent on their Ghyben-Herzberg fresh water lens, which floats above sea water in the pervious coral, and is replenished by convectional rainfall. High islands are characterized by orographic rainfall and a distinct wet (east) – dry (west) pattern emerges reflected in spatial differences in agriculture, with taro (wet) and yams (dry) epitomizing the divergence. During normal conditions the western Pacific tends to be wetter the central and eastern parts, though this trend is reversed during El Niño events which give rise to serious droughts in the western Pacific, including devastating frosts in the Papua New Guinea Highlands, the most densely populated region in the country, dependent upon sweet potatoes. During drought events, water shortages become acute on atolls in particular, resulting in stringent rationing in some cases and the use of emergency desalinization units in the most extreme cases. In the most pressing circumstances, communities drink coconut water at the cost of copra production.

While the focus of this report is on climatic extremes and sea-level rise and variability, geological disasters must also be considered in a review of disaster risk reduction in PICTs. Many of the islands located along the plate boundaries in the western part of the region are exposed to very high levels of seismological activity and there are several active volcanoes. Tsunami is a risk to all PICTs, but for those near to seismologically active areas, tsunamis pose a greater threat given the short warning time available. The magnitude of tsunami events may be increased by sea level rise and by coral reef degradation linked to warming temperatures

Changing vulnerabilities

Communities in PICTs traditionally had a range of measures that helped them to cope with the suite of disasters in the region (Campbell, 1985; 1990; 2006). While some of these measures may have been purposeful adjustments to a hazardous environment it is likely that many were incidental. Food security was sustained by producing surpluses which were dry stored (especially yams), fermented (especially taro and breadfruit), baked and dried. Diverse agro-ecosystems and garden fragmentation reduced overall vulnerability to extremes and famine foods were regularly eaten when shortages occurred. In many parts of the region dwellings were built with hipped roofs, strongly lashed posts and limited spaces for air to enter during high wind events. The *fale* and *bure* of Samoa, Tonga and Fiji were particularly wind resistant. In Fiji, traditional houses are built on a mound known as a *yavu* some being several metres high, depending on the status of the household. While not a purposeful disaster reduction measure, *yavu* helped protect houses from river and coastal flooding. Traditionally, many high island communities lived inland on fortified ridges, for example, but were encouraged to move to the coast to facilitate colonial and missionary objectives, and increasing exposure to storm surges. The region was covered by a complex patchwork of traditional exchange networks prior to colonization. Many of these networks were held together by traditional political and cultural practices and were maintained by the exchange of surplus production.

With the advent of colonialism these measures began to decline. A new religion, for example, undermined the rationale for some of the exchange networks and the cash economy enabled communities to purchase food rather than store it. The main commercial crop, coconuts for copra production, took land away from food crop production and introduced a vulnerable component to the cash economy: coconut palms, while resilient to high winds, often lose their fruit which can take up to seven years to regenerate (a long period without commercial income). With the expansion of commercial agriculture, subsistence farming has been constrained and in many areas soil fertility has declined and tapioca has become the dominant crop replacing the more nutritious and wind resistant taro and yam staples. Surplus food production is now uncommon in the region. Ironically, tapioca was introduced to many PICTs as post-disaster rehabilitation planting material.

Disaster relief began in the colonial period but tended to be ad hoc. Nevertheless, it contributed to the neglect of many of the traditional measures. Food preservation declined as has use of famine foods. With the advent of independence, relief became more important. Newly independent governments faced with disasters increased the provision of relief and became increasingly dependent upon externally derived assistance. Over the past decade the scale and scope of relief operations have increased significantly with coordination by UNOCHA and UNDP, the involvement of a large number of NGO humanitarian organizations and internet appeals launched within hours of the major events' occurrence. While contemporary Pacific Island communities have lost many of their traditional coping mechanisms and have become increasingly reliant on relief they still show a remarkable degree of resilience in the face of disaster.

Urbanization, the rate of which has increased rapidly in the past two decades (Connell and Lea, 2002), is also changing the nature of vulnerability in many PICTs. As urban populations grow so do the size of the squatter settlements which are often characterized by houses that are highly vulnerable to wind damage and are often located in flood (river and coastal) prone low-lying areas or on steep and unstable slopes. Urban planning is poorly developed in much of the region and where it is practiced often natural hazards are not a key consideration. At the same time most current disaster risk management in PICTs has a rural focus and while some coping mechanisms remain in rural areas, they are less likely to be maintained in the towns. Climate change induced migration is likely to cause further increases in urban populations exacerbating urban disaster vulnerability.

Impacts

The main impacts from climatic extremes in PICTS are damage to structures, infrastructure and crops during tropical cyclones and crop damage and water supply shortages during drought events. On atolls, salinisation of the freshwater lens and garden areas is a serious problem following storm surges, high wave events and 'king' tides. In the 2000s there were 56 disaster events listed in the ReliefWeb (2010) disaster history records. However, because five of these events affected more than one country there are 69 disasters listed for the period at the national level. Of the 56 events 35 were climate related (although four of the remainder were landslides which may have been triggered by heavy rains or by seismic activity). Two of the remaining 17 geological were tsunamis the effects of which may be increased by sea level rise and coral degradation. While the data are variable, and sometimes approximate, the death toll in the region in the same period of time was around 566 people of which 324 (57 per cent) were in climate related events. These events affected at least 690,000 people (97 per cent) and 66,000 were displaced (56 per cent). The availability of data, especially for smaller events, falls away prior to 2000, although in the previous decade 14 major climate related events resulted in 96 fatalities although during this period there was a severe and widespread drought associated with the 1997-98 El Niño event although there are no data on any fatalities.

Disaster Management
As noted earlier, most disaster management in the colonial era tended to be ad hoc and reactive. Fiji, was the first independent country to establish a programme, known as the Prime Minister's Hurricane Relief Committee which operated through to the 1980s by the Pacific Island Development Programme. At the regional level, the Pacific Disaster Preparedness Project was established in the early 1980s and it produced manuals, conducted workshops and carried out demonstration project (e.g. on building a hurricane resistant house). The next significant step was the establishment of the UNOCHA South Pacific Programme Office (SPPO) which instigated a number of activities including training of disaster management personnel throughout the region and provision of assistance for the establishment of national disaster management offices (NDMOs). The activities of the SPPO were later taken over by SOPAC which is now the home for regional disaster risk reduction activities. It is noteworthy that CCA falls under the mandate of SREP. As a result of the various regional activities most PICTs have NDMOs and a well trained cadre of disaster management officers. However, DRR still remains marginalized among the government activities of most countries and most disaster response remains in the management of relief and recovery operations. Since 2008, SOPAC has sought to have DRR better integrated into government activities by engaging with top level economic planners in the region.

Major investments in disaster preparedness and response in recent decades in the Pacific small island states have resulted in a decline in the number of fatalities per disaster. However, population growth and relocation, often into risk areas, have contributed to an overall trend of more people being affected by disasters. Encouragingly, economic losses per disaster have also been consistently low in recent decades (Hay and Mimura, 2010).

4.5.11. The Overall Links between Regions and Hazard Impacts

[Pending - Not sure if this is necessary]

4.5.12. Comment on 4°C Rise

Global warming at the level of 4°C is projected to render regional distribution of impacts negative for most regions. It should be stressed that the global warming of 4°C does not leads to a uniform warming – a much higher warming would take place in the Arctic. Regions specially affected by climate change are (IPCC Working Group II, 2007):

- The Arctic, because of high rates of projected warming on natural systems
- Africa, especially the sub-Saharan region, because of current low adaptive capacity as well as climate change
- Small islands, due to high exposure of population and infrastructure to risk of sea-level rise and increased storm surge
- Asian megadeltas, such as the Ganges-Brahmaputra and the Zhujiang, due to large populations and high exposure to sea level rise, storm surge and river flooding.

A 4°C warming would substantially aggravate negative impacts in the regions specified above, and produce negative impacts for most other regions.

4.6. Total Cost of Climate Extremes and Disasters

4.6.1. Introduction and Conception

The following subsection focuses on the economic impacts of weather extremes and disasters on humans, societies and ecosystems. These comprise of observed and projected future economic impacts, including economic losses and expected losses. Findings come from assessing the related literature as well as on evidence from former chapters (e.g., Chapter 3) and earlier subsections in this chapter.

To keep an integrated framework with the following chapters that mainly focus on risk management and adaptation issues, a conceptual introduction with key definitions covering both disaster risk management (DRM) and climate change adaptation (CCA) is given first. The typology of extremes, regions and sectors is based on the above contents. It is noticed that there are differences in economic impact and adaptation costs for developed and developing countries. Section 4.6.2 discusses methodologies for evaluating the costs of disasters, risks and adaptation. Section 4.6.3 explores the observed economic loss of particular extremes at the regional and global level with evidence from some key economic sectors. Section 4.6.4 discusses an aggregate estimate of global loss of a 4°C rise.

Key messages

Although the attribution of the increasing number and cost of weather disasters to climate change is still inconclusive, some general empirical trends of the economic impacts of weather disasters have been found; the absolute direct physical and economic losses from weather disasters have been increasing, together with per capita asset values. Indirect and secondary impacts are increasingly recognised but still not fully recorded. It should be noted that there are different scales of economic impacts of extremes among regions, sectors and social classes. It is likely that there is a negative correlation between proneness to disasters and stage of development, which is partly a cause and effect of the capacity gap between developed and developing countries.

There is much evidence that population growth and socio-economic structural shifts are the most important factors behind increasing losses from weather related extremes, especially in developing countries. This implies an imperative to incorporate reduction of economic impacts in long-term adaptation and development planning.

Disaster impacts can be devastating, particularly in heavily exposed low- and middle-income countries, and especially to the vulnerable within those countries. Because of the adaptation deficit in developing countries, they face increasing exposure to both population and assets risks during the process of urbanization and economic development, without full capacity to address social and economic vulnerability. For those more resilient rich countries, economic assessment is also very important to protecting their accumulated capital assets.

4.6.1.1. Conceptual Framework: Key Definitions

As mentioned in former chapters, extremes should be treated as physical events, and it is the economic and social impacts resulting from weather or climate events that become a disaster. Disasters are defined as extreme impacts associated with a severe disruption of the normal, routine functioning of the affected society, but disaster may also arise from a concatenation of physical, ecological and social responses to lesser physical events.

Cost of climate extremes and disasters: the net losses and benefits (in terms of avoided and reduced losses) of a specific extreme or disaster, including both disaster loss and cost of disaster management and adaptation.

Economic loss/damage cost of climate extremes: the net economic impact of extremes and disasters on human, society and ecosystems. This can be an observed or modelled impact. The damage cost or economic loss of extremes and disasters can be identified by impacts with the following classification: direct and indirect loss, tangible and intangible loss, market and non-market loss, etc. The distinction between direct and indirect is important, as most impact estimates available cover direct losses only, for instance insurance industry estimates. Indirect losses are however equally important, as they encompass in many cases a large share of overall losses, and also indicate the longer term economic impact of disasters. [References forthcoming]

Direct impacts are those caused by direct effects or the first-order consequences that occur immediately after a disaster-inducing event, usually inside the affected area. In some cases, direct losses have accepted market values that can be observed, such as the cost of destroyed buildings, roads and crops; direct impacts are generally a change in stock. Some approaches define impacts such as business interruption, or changes in the flow of goods and services as direct impacts as well. Here we see that while direct impacts may be comparatively easy to measure, accounting methodologies are not standardized and assessments are often incomplete. It is essential that the approach taken in any loss assessment is absolutely clear on its treatment of loss to avoid issues relating to, for example, double counting of stock and flow loss. [References forthcoming]

Indirect impacts include secondary and induced impacts that occur later in time in the affected location, as well as outside the directly affected location. They are caused by indirect and secondary effects which emerge later, including those that may be more difficult to attribute to the disaster event. These include both negative and positive factors, such as mental illness or bereavement resulting from disaster shock, and rehabilitation, health costs, reconstruction and disaster proof investment, including new employment in a disaster-hit area (disaster recovery booming). As the second-order consequences of disaster, indirect losses can be estimated by multiplier effects on for example, employment or investment for an economy. [References forthcoming]

Tangible and intangible impacts: Both direct and indirect impacts include tangible and intangible losses. Tangible losses are those that can be valued in the market place because they represent monetary production-based assets with monetary values, such as houses, vehicles, crops, facilities and so on, as well as loss of business income. Intangible losses do not have observable values in the market place and must be estimated using valuation techniques. Intangible damage comprises loss of life/morbidity (usually estimated using value of statistical life benchmarks), air and water pollution, ecosystem services, environmental amenity, and migration. Ecosystem services are functions performed by natural ecosystems that benefit humans such as carbon sequestration, air and water purification, sources of new medicines etc. [References forthcoming]

Direct impacts are not always the most significant outcome of disaster, in fact indirect impacts and unvalued intangible loss could far outweigh direct impacts. However, due to data availability and methodology, in many cases, mainly direct losses and tangible losses are covered in the estimates (Albala-Bertrand, 1993; Tol, 1994; Masozera et al, 2007; Schmidt et al, 2009; Hall et al, 2003; Huigen and Jens, 2006).

Probabilistic loss (Risk): Disaster risk is defined as “the potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.”(UNISDR, 2009a*)*. Risk is generally measured by a probability distribution of impacts and can be summarized by risk metrics such as the expected value and variance. Expected loss is defined as the aggregation of large and small possible loss events multiplied by their probability, mathematically the integral under a loss-probability curve. For extremes, which exhibit “fat tails”, i.e. the expectation alone is usually not a good metric to use, and using other metrics such as the variance is helpful. Although uncertainty issues and methodological gaps relating to risk assessment remain, there are some estimates of the historic and future global losses from weather extremes.

Adaptation cost: the cost of planning, preparing for, facilitating, and implementing adaptation measures including transition costs. (IPCC, 2001),, or cost for the actions on coping (Emergency/Disaster Response), recovering (Rehabilitation/Reconstruction), and anticipating/preparing (Preparedness, Warning Systems, Risk Retention and Transfer) (see Section 2.6).

Adaptation deficit: Identified as the gap between current and optimal levels of adaptation to climate change events or extremes (Burton and May, 2004).

4.6.1.2. Framework to Identify the Economic Impacts of Climate Extremes and Disasters

It has been argued widely that the mutual goals of DRM and CCA should be integrated in theory and practice because of intrinsic inter-linkages and their dynamic relationship (Burton and Van Aalst, 2004; Bouwer et al., 2007). While this is important, it is also important to note that they are different in a number of respects. DRM has traditionally focused on responding to and coping with disasters, and reducing damages. The total damage cost can be separated into avoidable and residual damage costs. The residual damage cost is the cost that would be not avoided even with a very high adaptation investment. The avoidable damage cost can be taken as the gross benefit of risk management, which may be feasible but not economically efficient (Parry et al., 2009; Pearce et al, 1996; Tol, 2001). Adaptation can be addressed within an iterative risk management framework, representing actions that have the effect of reducing exposure and vulnerability under anticipated climate change, as emphasized in the IPCC's Fourth Assessment Report (IPCC 2007) (see Chapter 1), and compared to estimated damage costs to be avoided.

CCA typically takes a longer term and dynamic perspective, compared to DRM, the latter assuming stationarity in the occurrence of weather hazards. DRM initiatives that emphasize, for example, increasing community resilience via income diversification, have benefits for disaster adaptation, but would also have wider benefits to the community that may contribute to CCA due to increased economic activity and wealth. As some studies have suggested, it is necessary to build connections between disaster protection investment and socio-economic development to reduce risk (Changnon, et al.; Rose, 2007).

It is not easy to avoid the "poverty trap" for many developing countries with inadequate stock of built, natural, social and human capital. Unless properly integrated and targeted, poverty reduction policies and goals will in themselves not address the specific climate change related risks for the most vulnerable people in developing countries. As stated by Adger et al (2001, pg193.) "the competing objectives of sustainable development are both highlighted and exacerbated by the dilemmas of climate change". Hence it is imperative to peruse integrated development, CCA and DRM initiatives that allow for co-benefits that build resilience and promote sustainable development. This requires theoretical and practical integration between the fields of DRM, CCA and development because of their intrinsic interconnectedness and complex feedback relationships.

4.6.1.3. Differing Economic Impacts in Developed and Developing Countries: The Empirical Evidence

The economic causes and repercussions of disasters have been well understood since Sen's (1981) seminal work on the social phenomena of drought and famine. For example, Bension and Clay (2004) have taken drought as a phenomenon of economic significance, with results such as sharp reduction in agricultural production, decline in rural income, reduced exports and employment, as well potential multiplier effects on the monetary economy. Also, the relationship between macroeconomic and climatic disasters has been explored with statistical and comparable analysis in recent years (Tol and Leek, 1999; Burton, et al, 1993; Albala-Bertrand, 1999; Kahn, 2005; Benson and Clay, 1998, 2003; Kellenberg and Mobarak, 2008; Rasmussen, 2004; Toya and Skidmore, 2007; Raschky, 2008; Lester, 2008; Noy, 2009).

Key determinants of economic impacts. The scale and magnitude of the economic impacts of natural disasters are determined by some key factors (OAS, 1991; Mechler, 2004; Gurenko, 2004, Cummins and Mahul, 2008; Benson and Clay, 2004): (i) natural hazard exposure: (ii) economic vulnerability – structure of economy, GDP, tax revenue, domestic savings and mature of financial markets, access to external finance, etc; (iii) geographical areas; (iv) technical and scientific development, (v) concentration of economic activity centres (e.g. large urban agglomerations) exposed to natural hazards.

The concentration of risk generally has a geographical focus (Swiss Re, 2008), and in particular developing countries are more vulnerable to climate change than developed countries. This is mainly because: (i) developing countries have less resilient economies since they depend more on natural capital and climate-sensitive activities (cropping, fishing, etc) (IPCC, 2007); (ii) they are often poorly prepared to deal with the climate variability and natural hazards they already face today (World Bank 2000); (iii) more damages are caused by mal-adaptation due to the absence of financing, information, techniques in risk management and week governance systems (Benson and Clay, 1998); (iv) there is less consideration of climate proof investment in regions with a fast growing population and asset stock (such as in coastal areas) (OECD, 2008; IPCC, 2001b). In particular, the adaptation deficit resulting from the level of economic development is considered as an important issue contributing to the gap between developed and developing countries (World Bank, 2007).

Macroeconomic and developmental impacts. It has been conceived that natural disasters may have some economic impacts on the pace and nature of development (Benson and Clay, 1998, 2003; Kellenberg and Mobarak, 2008;). Key adverse macroeconomic impacts experienced include reduced direct and indirect tax revenue, dampened investment and reduced long term economic growth through the negative effect on a country's credit rating and an increase in interest rates for external borrowing. With GDP and loss of life as major indicators of disaster impact, a growing literature has emerged that identifies important adverse macroeconomic and developmental impacts of natural disasters (Cochran 1994; Otero and Marti, 1995; Benson, 1997a,b,c; Benson and Clay, 1998, 2000, 2001, 2004; ECLAC 1982, 1985, 1988, 1999, 2002; Murlidharan and Shah, 2001; Crowards, 2000; Charveriat, 2000; Mechler, 2004; Hochrainer, 2006).

In general, the relationship between development and disaster impacts means a wealthy or richer country relates to a safer country, since a higher income level, governance capacity, higher education rate, climate proof investment and insurance system reduce the damage costs of disasters (Wildavsky, 1988; Rasmussen, 2004; Tol and Leek, 1999; Burton, et al, 1993; Albala-Bertrand, 1999; Toya and Skidmore, 2007; Raschky ,2008; Brooks, Adger, Kelly, 2005; Kahn, 2005; Lester, 2008; Noy, 2009). In some cases an inverted 'U' shape curve of the total impact over GDP per capita has been identified (Lester, 2008; Kellenberg and Mobarak,2008)**.** This implies that the countries most at risk of disaster will tend to be middle-income economies, since least developed countries tend to have simpler economic structures (Benson and Clay,1998). However, it may also indicate that middle-income countries invest relatively less in disaster prevention than high-income countries (Kellenberg and Mobarak, 2008).

There is an emerging consensus that, on average, natural disasters have a negative impact on short term economic growth (Cavallo and Noy, 2009; Raddatz, 2007; Noy, 2009). With a few exceptions, which consider disasters rather a problem of, but not for development (Albala-Bertrand, 1993, 2006; Caselli and Malhotra, 2004; Skidmore and Toya, 2002).

In the long run, despite inconclusive evidence, some researchers argue that poorer developing countries and smaller economies are likely to suffer more from future disasters than developed countries, especially in relation to large disasters (Raddatz, 2009; Hallegatte et al, 2007; Hallegatte and Dumas, 2009; Heger et al, 2008; Loayza et al, 2009). While the countries with highest income account for more of total economic and insured losses of disasters (Swiss Re, 2010), a greater portion of GDP and a higher fatality are seen in developing countries, which imposes a higher burden on governments and individuals in those poor countries. For example, during the 25 year period from 1979 to 2004 over 95% of natural disaster deaths occurred in developing countries and direct economic losses averaged US$54 billion per annum. (Mechler, 2010; Freeman, 2000; World Bank, 2001; Cavallo and Noy, 2009).

Some emerging developing countries, such as China, India and Thailand will likely face increased future exposure to extremes especially in highly urbanised areas, as a result of the rapid urbanization and economic growth (OECD, 2008; Bouwer et al., 2007). As one important case in point, in Fiji, natural disasters have resulted in reduced national GDP as well as decreased human development conditions as captured by the human development index (see Lal et al., 2009). In a case of Mexico, natural disasters saw HDI regressing by approximately two years development with increasing poverty levels (Rodriguez-Oreggia et al, 2009).

Also, in more developed economies important yet less pronounced effects have been detected. For example, in some cases a "creative destruction" was found, but only occurs in countries with high income level due to knowledge spillovers and new technology introduction (Cuaresma et al, 2008). However, the fiscal and trade deficits could deteriorate in the aftermath of climatic events both in developing and developed countries (Hegar et al, 2008; Mechler et al.2010). Mechler et al (2010) found that disasters pose significant contingent liabilities for governments (further discussed in 6.3) and prudent planning is necessary to avoid debilitating consequences as shown by the Austrian political and fiscal crisis in the aftermath of large scale flooding leading to losses of 3 billion Euro in 2002.

Costs and impacts not only vary among developing and developed countries, but between and within countries, regions and local areas due to heterogeneity of vulnerability and resilience. Some individuals, sectors, and systems would be less affected, or may even benefit, while other individuals, sectors, and systems may suffer significant losses in a same disaster. For example, women and children are found more vulnerable to disasters with lager disasters having an especially unequal effect (Neumayer and Plumper, 2007).

4.6.2. Methodology and Literature for Evaluating Disaster and Adaptation Costs and Impacts

DRM decisions are made under resource scarcity, and as such the cost effectiveness of adaptation and mitigation initiatives needs to be established. The mainstay for this analysis is credible estimates of the monetary value of the impacts of disasters and adaptation or mitigation efforts.

There are two major approaches for the economic valuation for the impacts caused by extremes and disasters at the regional and global level: a top-down approach and a bottom-up approach. The top-down approach is grounded in macroeconomics and often utilises general equilibrium modelling with regional or global statistic data. A bottom-up approach, derived from microeconomics, scales up data from sectors at the regional or local level to aggregate an assessment of disaster costs and impacts (see Van der Veen, 2004). Distinction can also be made between the DRM community and the CCA community, the former traditionally relying on bottom up approaches using catastrophe loss modelling (CLM, similar to the insurance industry); and the latter typically using integrated assessment models (IAMs) and economic models (a.o. CGE).

How disaster impacts are evaluated depends on numerous factors, such as the types of impacts being evaluated, the objective of the evaluation, the information and data available, and the spatial and temporal scale under consideration. It is important to note that macroeconomic approaches such as general equilibrium models look only at market dynamics and as such do not capture intangibles such as impacts on ecosystems.

While both macro- and microeconomic approaches to disaster loss assessment tend to delineate between direct and indirect costs, these are generally defined somewhat differently (Van der Veen, 2004). As discussed above, it is essential that policy-makers and practitioners are aware of these definitions of disaster impacts, and are consistent in their approach.

Welfare economics and disaster impact assessment. The bottom-up approach to disaster impact assessment attempts to evaluate the impact of an actual or potential disaster on consumer surplus. This approach values direct loss of or damage to property, as well as that of the interruption to the economy, impacts on health and wellbeing, on environmental amenity and ecosystem services. In short, it attempts to value the impact of the disaster to society. These approaches are rooted in a cost-benefit analysis framework (Van der Veen, 2004).

The first step in disaster impact assessment of this kind is to establish the spatial and temporal scale of the analysis. This is essential to economy-wide analysis to ensure the credibility of the estimate. For example, if a business in a disaster affected area experiences loss in infrastructure and potential trade, this may intuitively be considered a loss. However, if competing business within the analysis area picks up that trade instead, the net loss to the area is zero. Similarly, if a business that could not trade during the immediate aftermath of the disaster is able to recoup lost business at a later time – that is still within the temporal frame of the analysis – then this is not a loss (Handmer *et al*, 2002). Because disaster loss assessment attempts to evaluate the total, net impact of the disaster it is essential that any positive impacts, such as post-disaster boom spending are accounted for in the analysis.

Analysts must be clear and consistent in their treatment of costing property and infrastructure loss. While methodologies based on insurance practice sometimes use replacement value for costing damage, it may be more appropriate to use depreciated values, with the focus on the actual market value of the damaged asset (Handmer *et al*, 2002).

It may be that the largest impacts of disasters are the intangible losses such as ecosystem services, anxiety, heritage etc. These impacts are considered intangible because there is no direct market for them, and as such their values cannot be directly observed in the market place. There is however a body of work dedicated to attaching a monetary value to intangibles so that they may be included in impact assessments and cost-benefit analysis (TEEB, 2009, Pagiola *et al*, 2004).

The impact of increased air and water pollution, for example, can be estimated by looking at the cost of health care induced by this pollution increase. The 'Travel Cost' method estimates environmental amenity by looking at what people are willing to pay to visit an ecosystem. Similarly, hedonic pricing methods model the value of environmental amenity, scenic beauty or cultural values associated with environmental features. Stated preference methods such as contingent valuation use surveys to estimate the value people place on environmental intangibles (Pagiola et al. 2004). While there remains criticism of the use of contingent valuation, if carried out properly it can be a very useful tool (see Carson *et al*, 2003).

Unfortunately the cost of obtaining credible estimates for the value of intangibles is often prohibitive. In these instances benefit transfer techniques are available, where the values obtained from one study of a particular environment can be used in another evaluation. Benefit transfer is useful because it is cost effective, however practitioners must ensure the transfer is appropriate (Ready and Navrud, 2006).

Modeling disaster impacts and risks. Modeling disaster impacts generally involves generating an estimate in terms of risk, i.e. using probability based metrics. There is a substantial, yet very heterogeneous body of modeling research on the economic impacts by the DRM community. Most studies have focused on impact assessment remodeling actual events in the past and aiming at gauging to estimate the different, often hidden follow on impacts of disasters (e.g. Yezer and Rubin, 1987; Ellson et al., 1984; West and Lenze, 1994; Brookshire et al., 1997; Chang et al., 1997; Guimaraes et al., 1993; Rose 2007; Okuyama, 2008; Hallegatte et al., 2007). Existing approaches utilize a plethora of models such as Input-Output, CGE, economic growth frameworks and simultaneous-equation econometric models. Only a few models have aimed at representing extremes in a risk-based framework in order to assess the potential impacts of events if certain small or large disasters should occur (Freeman et al., 2002a; Mechler, 2004; Hochrainer, 2006; Hallegatte and Ghil, 2007; Hallegatte, 2008).

Analyses considering climate change in economic impact and risk modelling have only emerged over the last few years, and, as reported in 2007 by Solomon et al. much of the literature remains focussed on gradual changes such as sea-level rise and agricultural effects. Further, based on work by Nordhaus and Boyer (2000), extreme event risks in adaptation studies and modeling have usually been represented in a rather ad hoc manner, using add-on damage functions that are based on averages of past impacts and contingent on gradual temperature increase.

In most impact and modeling studies on extreme event risks, the focus has generally been on tangibles such as impacts on produced capital and the economy. Intangibles such as loss of life and impacts on the natural environment are generally not considered using monetary metrics (see Parry et al., 2009). Loss of life due to natural disasters, including future changes, however is accounted for in some studies (e.g. Jonkman, 2007; Jonkman et al., 2008; Maaskant et al., 2009). As also reported by Parry et al. (2009) when accounting for both tangible and intangible real impacts, and thus the adaptation costs, these are likely to be much larger than simple tangibles estimates.

4.6.. Estimates of Global and Regional Costs

Much work has been conducted on the analysis of direct economic losses from natural disasters. The examples mentioned below mainly focus on national and regional economic loss of particular weather extremes and disasters, and also discuss some uncertainty issues related to the economic impact assessment.

4.6.3.1. The Regional and Global Economic Loss of Climate Disasters

[Some conclusions should be reflected from Chapter 3 of the SREX report here]
Over the past decades the number and impact of reported extreme events has been increasing, both in terms of mortality and overall economic loss. In particular, the increasing trend for weather related disasters has been more pronounced than for non-weather disasters (Munich Re, 2008; Swiss Re; 2008; 2009; 2010). Some suggest that the changing frequency of extreme weather is already noticeable in loss records (e.g. Mills, 2005). Others however argue that exposure and vulnerability to different types of hazards has evolved differently over time (e.g. Kellenberg and Mobarak, 2008; Bouwer, in press).

[INSERT FIGURE 4-18 HERE:
Figure 4-18: The overall losses and insured losses from natural disasters worldwide (adjusted to present values).]

The unequal distribution of the human impact of natural disasters is reflected in the number of disasters and damage losses between regions (see Table 4-17). The Americas suffered the most economic damage from climatological, meteorological and hydrological disasters, accounting for a highest proportion of 54.6% of the total damages, followed by the Asia (27.5%) and Europe (15.9%). Africa accounted for only 0.6% of global economic damages (annual average) from climatic related disasters in the 2000-2008 (Vos et al, 2010).

[INSERT TABLE 4-17 HERE:
Table 4-17: Climate related disaster occurrence and regional average impacts from 2000-2008. Sources: Vos F, Rodriguez J, Below R, Guha-Sapir D. *Annual Disaster Statistical Review 2009: The Numbers and Trends*. Brussels: CRED; 2010. page 5-7, page25.]

When expressed as a proportion of exposed GDP, estimated losses of natural disasters (predominantly hydro-meteorological disasters) in developing regions, especially in East and South Asia and the Pacific, Latin America and the Caribbean, are several times higher than those in developed regions. This indicates a far higher vulnerability of the economic infrastructure in developing countries (UNISDR, 2009b; Cavallo and Noy 2009) (see Figure 4-19). For example, OECD countries account for 71.2% of global total economic losses of tropical cyclones, but only suffer 0.13% of estimated annual loss of GDP from 1975-2007 (UNISDR, 2009b).

[INSERT FIGURE 4-19 HERE:
Figure 4-19: Distribution of Regional damages as a % of GDP (1970-2008). Source: EM-DAT, WDI database, calculated by Cavallo and Noy (2009).]

The general consensus is that the affected regions are vulnerable both because of climate-related extremes and their status as developing regions (Burton et al. 1993). A series of developing countries, such as Argentina, Ecuador, Honduras, Nicaragua, China and Brazil, have been identified as vulnerable countries for who losses from floods could be expected to exceed or approach 1% of GDP (Swiss Re, 1998; 2009).

Studies at the global or regional level are discussed per region and for different hazards below (Bouwer, in press). The collective picture is still fragmented given the difficulty in attributing causes of fluctuations in economic losses from disasters and an imbalanced spatial coverage of literature, which is skewed mostly toward developed countries and the northern hemisphere.

4.6.3.2. Africa

The frequency and intensity of extreme events, such as floods and droughts, has increased in Africa over the past few years (IPCC, 2007). This has caused major disruptions to the economies of many African countries, thus exacerbating continental vulnerability [This section needs to align with Chapter 3] (Washington et al. 2004; AMCEN/UNEP 2002). Since 1975-2007, the estimated average annual economic loss of tropical cyclones and floods accounted for 0.55% and 0.19% of GDP respectively in affected Sub-Saharah Africa countries, which indicates a higher exposure under an increasing occurrence of disasters (UNSIDR, 2009b).

Agriculture contributes approximately 50% to Africa's total export value and approximately 21% of its total GDP (Mendlesohn et al., 2000; PACJA, 2009). With the least efficient agriculture industry in the world, increasing variability in seasons, rainfall, drought and weather extremes is making Sub-Saharan Africa extremely vulnerable. This vulnerability is exacerbated by poor health, education and governance standards (Brook, Adgar and Kelly, 2005).

Some studies project that extreme events might increase in many desert regions in southern Africa (Scholes and Biggs 2004).

Drought: One third of Africans now live in drought-prone areas, mainly in the Sahel, around the Horn of Africa and in southern Africa. Drought will also cause a decline in tourism, fisheries and cropping (UNWTO, 2003). This could reduce the revenue available to governments, enterprises and individuals, and hence further deteriorate the capacity for adaptation investment. For example, the 2003/4 drought cost the Namibian Government N$275 million in provision of emergency relief. Cameroon's economy is highly dependent on rain-fed agriculture, a 14% reduction in rainfall is projected to cause significant losses, of up to around US$4.65 billion (Molua and Lambi, 2006).

Flooding: Costly damage to African port cities from flooding, storm surge and high winds is predicted under climate change. For instance, it is indicated that in Alexandria, US$563.28 billion worth of assets could suffer damage or be lost because of coastal flooding alone by 2070 (Nicholls et al., 2007).

Ecosystems: Disasters are likely to have some negative impacts on biodiversity and the tourism industry. Projected climate impacts on Namibia's natural resources would cause annual losses of 1-6 per cent of GDP, from which livestock production, traditional agriculture and fishing are expected to be hardest hit, with a combined loss of US$461-2,045 million per year (Reid et al, 2007).

4.6.3.3. Asia

According to statistics collected by the insurance sector, about one third of reported catastrophes globally occur in Asia, while the proportion of fatalities is about 70% (Munich Re, 2008). Since 1980, more than 1 million people perished in Asia due to natural catastrophes, more than in all other continents combined (Spranger, 2008). While accounting for cultural, political and historical factors, some relationship between wealth and protection can be found in different locations in Asia. In the light of the fact that Asia is a rapidly emerging region in global economy, it would be particularly useful to incorporate climate extreme preparedness into long-term sustainable development planning. Some studies argue that economic restructuring and the process of market transition in those fast developing Asian countries could potentially help to decrease vulnerability and economic impacts of disasters (Adger, 1999; OECD, 2008).

Flooding: The geographical distribution of flood risk is heavily concentrated in Asia, especially in India, Bangladesh and China. In South Asian countries, flooding has contributed 49% to the modelled annual economic loss of GDP since the 1970s (UNISDR, 2009b). Chang et al. (2009) studied historic changes in economic losses from floods in urban areas in Korea since 1971, and found an increase in losses after correction for changes in population only. Fenqing et al, (2005) analysed losses from flooding in the Xinjiang autonomous region of China, and found an increase that seems to be linked to changes in rainfall and flash floods since 1987.

Many parts of Asia have rapid population growth and concentration of people and infrastructure in coastal areas, particularly in some of the largest cities in the world, which increases the potential losses from extreme weather events (IPCC 2001b; 2007b). Focusing on 136 large port cities around the world that have more than one million inhabitants, OECD (2008) estimated the exposure of economic assets and population to coastal flooding, and found that Asia has both a high number of cities (38%) and high exposure per city when compared to other continents. 17 Asian cities among the global top 20 largest (in terms of inhabitants) are projected to see more than a 200 per cent increase in exposure by 2015, compared to 2005. It is also estimated that, by 2015, loss potentials among the world's

10 largest cities, most of which are in developing countries, are projected to increase from 22% (Tokyo) to 88% in Shanghai and Jakarta (Bouwer et al, 2007), compared to 2005.

Typhoon: Tropical cyclone mortality risk is highly geographically concentrated in Aisa, and takes both a relative and absolute high exposure to population and GDP. For example, 75.5% of expected mortality due to typhoons is concentrated in Bangladesh and 10.8% in India. South Asian countries have an estimated average annual economic loss of $1054 million (2000 dollars) from 1975-2007 (UNISDR, 2009b). Possibly, the fast development and increasing risk awareness on some typhoon-prone areas could increase the protection levels in some developing Asian countries. This could partly explain why typhoon losses in China since 1983 do not show a trend after correction for increases in wealth (Zhang et al., 2009). Similarly, normalised losses from typhoons on the Indian south-east coast since 1977 show no increases (Raghavan and Rajesh, 2003). These findings may be exceptional and could not be used to generalise with a higher confidence since estimating an aggregate effect on long-term economic growth and welfare is difficult and controversial.

Drought: Asia has a long history of drought, which has been linked with other extreme weather events (Science Daily, 2010). In the spring of 2010 severe droughts impacted some east and southeast Asian countries, causing damages to crops, a drop in river water levels and reservoirs, and economic losses. According to China's State Commission of Disaster Relief, 51 million Chinese are affected by the drought, with estimated direct economic losses at US$2.8 billion. As reported by the Philippine Department of Agriculture's Central Action Center (DACAC), the total damages have reached US$244.4 million, with the damage in paddy rice production already nearing 300,000 metric tons (Xinua, 2010). [Peer reviewed references forthcoming]

The health sector bears a significant share of the economic burden of disasters, and health infrastructure recovers at a slower rate than infrastructure in other sectors. The emergence of infectious diseases, environmental pollutants and health inequality is likely to be exacerbated by rapid urbanisation; it is argued that health related risks could potentially worsen in Asian countries (Wu et al., in press).

4.6.3.4. Europe

Weather disasters such as flooding, droughts, forest fires and heat waves will very likely have different economic impacts across and within European Union States. Understanding how vulnerability to extreme events varies between different sectors, people and at different scales is important to analysis of economic impacts (OECD 2008; O'Brien et al, 2004).

Storms: In 2009 Europe experienced the globally highest economic loss due to extreme events. The total losses exceeded USD $20 billion, of which storms accounted for the majority of these losses. Europe also ranked in the top three regions with the highest portion of the economic loss, about 0.11% of GDP, slightly higher than the world average level of 0.10% (Swiss Re, 2010).

According to a study by Swiss Re (2009), by the end of this century once-in-a-millennium storm surge events could well be striking Northern Europe every 30 years. This is likely to result in a disproportionate increase in annual expected losses of between 100% and 900%, depending on the country. The annual expected loss burden from surge events could range from a current Euro 0.6, to 2.6 billion by end of the century. As a result, adaptation through adequate sea defenses and the management of residual risk is essential.

Sectoral impacts: Some researchers have found no contribution from climate change to trends in the economic losses from floods and windstorms in Europe since 1970s (Barredo, 2009; 2010). Some studies have found evidence of increasing damages to timber in Sweden and Switzerland (Nilsson et al., 2004; Usbeck et al., 2010). Still other studies assert that increases in forest disturbances in Europe are mostly due to changes in forest management (e.g. Schelhaas et al., 2003). Furthermore, many studies have explored the sectoral impacts in different areas of Europe caused by climate change, such as agriculture, tourism, transport, health, biodiversity and others (Fewtrell, Kay, 2008; Kenyon, 2007; Maaskant, et al, 2009; Priceputu, GreppinA, 2005;). For example, FEEM estimated the welfare impacts of the ecosystem sector, and found that they can be as much as $145-170 billion USD (Nune, Ding, 2009). Studies of the economic impact of disasters are currently inadequate and require further empirical research and methodology to investigate how extremes may impact the economy, ecosystem services, environmental amenities and human welfare. The conjunction between climatic stresses and already cited impacts on economies and society will require well-planned adaptation strategies in Europe.

4.6.3.5. Latin America

Climatic disasters account for the majority of natural disasters in Latin America, with most of its territory located in tropical and equatorial areas. Low-lying states in Central America and the Caribbean are especially vulnerable to hurricanes and tropical storms, posing significant impacts for supporting infrastructure, public safety and fragile coastal ecosystems (Lewsay et al, 2004). In October 1998, Hurricane Mitch, one of the most powerful hurricanes of the Tropical Atlantic basin of the 20th century, caused direct and indirect damages to Honduras of $5 billion USD, equivalent to Honduras' total GNP in 1998; comparatively, Hurricane Fifi caused a 1999 equivalent of $1.7 billion USD of losses in 1974 (IMF 1999).

Some literature indicates that hurricane losses, when corrected for population and wealth in Latin America and the Caribbean have not increased since the 1940s (Pielke et al. 2003); and that increasing population and assets at risk are the main reason for increasing impacts. Nonetheless it is likely that natural disasters will remain a significant external shock to economies in this region in the next decades.

4.6.3.6. North America [only covers USA, further analysis on Canada and Mexico forthcoming]

Hurricanes and storms: Given the extremely large losses and importance for the national and international insurance industries, losses from hurricanes in the USA have been studied extensively. Since the 1970s an increase in losses is observed and this is related to the increase in hurricane activity since that time, largely attributable to natural variability. It is reported that the direct overall losses of Hurricane Katrina are about US$ 138 billion in 2008 dollars (Spranger, 2008). [Hurricane information needs to be brought in line with other chapter info on hurricane strength and frequency]

With a normalization procedure (principally corrections for wealth and population), some studies have found similar conclusions that no trends are found in the normalized loss record over the entire length of the record (starting in approximately 1900) (Collins and Lowe, 2001; Pielke et al., 2008; Miller et al. , 2008; Malmstadt et al., 2009; Schmidt et al., 2009).

Malmstadt et al. (2009) and Schmidt et al. (2009) however maintain that an anthropogenic climate change signal can be found in the normalised loss record for hurricanes. For example, since 1971-2005 economic losses of cyclones show an annual increase of 4% excluding socio-economic effects (Schmidt et al., 2009). Changnon (2009b) indicates that normalized insured losses from windstorms in the USA have increased, but only in areas where population and capital are concentrated most heavily. Changnon (2003) reveals annual average losses of $36 billion from extremes and gains averaging $26 billion when conditions are favourable (good growing seasons, mild winters, etc). Compared with various measures and values, it has been found that the impacts are relative small, typically about 1% of GDP.

Other extreme events: Smaller scale but more frequent storms events can together cause substantial losses. Changnon (2001) found increases in normalised losses from various thunderstorm storm events in the USA (hail, lightning, high wind speeds and extreme rainfall), but also in areas where no increase in thunderstorm activity occurred. This is also true for losses from tornadoes (Brooks and Doswell 2001; Boruff et al. 2003). This suggests there may be other causes for these loss increases. Changnon (2009a) finds similar conclusions for hail storm losses. Similarly, there are indications that flood losses in the USA have not increased since 1926 (Downton et al., 2005).

Weather stress: Chronic everyday hazards such as severe weather (summer and winter) and heat account for the majority of natural hazard fatalities. It has evidence that heat- and cold-related extreme weather is probably the deadliest weather hazards in the U.S based on a geographical and epidemiological research since 1970s (Borden, Cutter, 2008).

4.6.3.7. Oceania (Australia, New Zealand and Pacific Island Countries)

The Oceanic region, including Australia, New Zealand and the Pacific Island countries (PICs) is geographically, economically and socially diverse. Due to this diversity it is appropriate to briefly consider these three sub-regions individually.

Australia: The International Disaster Database (EM-DAT, 2010) estimates the total cost of disasters in Australia between 1970 and 2009 to be approximately $29 billion USD. The burden of disasters in Australia is not evenly spread, as a few large events dominate the overall cost, including Cyclone Tracy in 1974, the Newcastle Earthquake in 1989 and the Sydney hailstorm in 1999. Overall floods (29%), severe storms (26%) and tropical cyclones (24%) are the most costly natural disaster types in Australia. Bushfires in Australia are the most dangerous in terms of death and injury, however they only account for approximately 7.1% of the economic burden of disasters in the 1967-1999 period (BTE, 2001).

The cost of disasters is believed to be increasing in Australia; Crompton and McAneney (2008) found that the cost of insured losses is increasing over time. However, they found that the increase in insured losses over time can largely be explained by demographic and societal changes, rather than climate change.

Australia is predicted to experience an increased cost of disasters if current population growth continues, with the corresponding increase in the number and value of dwellings (Crompton and McAneney, 2008). Climate change is concurrently expected to increase the frequency and severity of extreme weather events (Alexander and Arblaster, 2009). These factors will converge to increase the cost, financial, social and environmental, of disasters in Australia unless disaster adaptation and mitigation efforts are increased.

New Zealand: Aggregates of the total cost of natural disasters in New Zealand are not easily estimated due to earlier lack of data collection and may be underestimated (BTE, 2001). EM-DAT (2010) estimated the total economic cost between 1970-2009 to be approximately $1 billion USD. Floods were the most common type of disaster in New Zealand, accounting for 43 % of the total number of events (BTE, 2001).

PICs: The southwest Pacific experiences periodic drought and extreme sea levels, largely due to El Niño-Southern Oscillation and El Niño events. Coastal areas in PICs also experience tropical cyclones, accompanied by high winds, storm surges and extreme rainfall (World Bank, 2000). EM-DAT (2010) estimates the cost of disasters in PICs between 1970 and 2009 to be approximately $3 billion USD. Three Pacific disasters are in the top ten disasters (1974-2003) for cost as a proportion of GDP, with the 1985 cyclone in Vanuatu costing approximately 139% of national GDP. This highlights how devastating disasters can be to small, developing countries (Guha-Sapir *et al, 2004).*

Not only are disasters in PICs devastating but they are also relatively frequent. Oceania accounted for 8% of all the disasters registered with EM-DAT between 1990 and 1999 (Alcántara-Ayala 2002, pg. 112), this indicates a significant burden of disasters considering the tiny proportion of global population that resides in PICs.

PICs are vulnerable to natural disasters for several reasons. Small islands are susceptible to disasters induced by extreme rainfall events. The small size of many PIC islands further compounds disaster risk because of a small natural resource base and a high concentration and competition for land use (Preston *et al*, 2006; Pelling and Uitto, 2001). PICs economies tend to be dominated by agriculture, which is particularly vulnerable to natural hazards (Narayan, 2003). Despite perceived vulnerabilities, Pacific Island peoples have a traditional resilience to disasters and have practising disaster risk management since pre-colonial times. Profound changes in the social, economic, cultural and political fabric of PICs have led to a decline in traditional disaster management practises (Campbell, 2006; Campbell, 2009). Much of this traditional resilience remains and could be reinvigorated within the current context to reduce vulnerability.

4.6.4. The Regional and Global Costs of Adaptation

Adaptation studies for developed and developing countries have focussed on the costs of adaptation rather than impacts and damage costs of extremes, with many studies not explicitly separating extreme events from slower onset events (see Parry et al., 2009; World Bank , 2009; EEA, 2007; ECA, 2009; Solomon 2007; Nordhaus, 2007; Parry et al., 2009; Agrawala and Fankhauser, 2008). Those studies considering extreme events, and finding or reporting net benefits over a number of key options (Parry et al., 2009; Agrawala and Fankhauser, 2008) do so by treating it in a similar way to gradual onset phenomena and use deterministic impact metrics, which is problematic for disaster risk. A recent, risk-focussed study (ECA, 2009) went so far as to suggest an adaptation cost curve, which organizes adaptation options around their cost benefit ratios with most cases in this report looking at sub-national level and one on national level adaptation.

One study (World Bank, 2009) aggregating at the sub-continental level with a focus up to 2050, specifically calculated adaptation costs for dealing with changes in extreme events; they estimate an annual value of about $6.5 billion USD. National level studies in the EU in the UK, Finland and the Netherlands as well as a larger number of developing countries using the NAPA approach have been conducted or are underway (Lemmen et al, 2008; MMM, 2005; Van Ierland, 2005; DEFRA, 2006; Parry et al., 2009). However the evidence base on the economic aspects, including economic efficiency, of adaptation remains limited and fragmented (Adger et al., 2007; Agrawala and Fankhauser, 2008; Moench et al., 2009; Parry et al., 2009).

Adaptation cost estimates can be split into four major categories (UNFCCC, 2007; SEI, 2008; PACJA, 2009): (i) Assessing vulnerability (building on assessments contained in NAPA); (ii) Building institutional capacity (climate information, skilled professionals, and so on); (iii) Piloting adaptation strategies; and (iv) Operational adaptation (needed to cope with new hazards and conditions). The existing estimates of adaptation cost have some weakness in methodology: a) omission of some economic sectors, such as ecosystems, tourism, etc, and b) a lack of consideration for “adaptation deficit” which is relevant to climate proof investment (PACJA, 2009).

It is necessary to incorporate an analysis of the chronic economic impact of catastrophes into the adaptation planning process (Freeman, 2000). A full assessment of disaster cost at varying spatial and temporal scales can set the stage for comparisons of post-disaster development strategies, which would make DRR planning and preparedness investment more cost-effective (Gaddis, et al, 2007). Also, costs of climate disasters can impact human, social, built and natural capital, and their associated services at different levels. For example, a cost estimate for financial vulnerability would represent a baseline for the incremental costs arising from future climate risks (Mechler et al, 2010). There is consensus on the important role of ecosystems on risk reduction and well-being, which makes the value of ecosystem services an integral part of key policy decisions (Costanza, Farley, 2007; Tallis and Kareiva, 2006).

Taking Africa as an example, based on various estimates the potential additional cost of climate proofing new infrastructure would likely amount at a range of US$3-10 billion per year by 2030 (Reid et al., 2007; UNFCCC, 2007; PACJA, 2009). However, this could be also an underestimate considering an increasing climate protection for improving Africa’s low resilience to climate extremes as well international humanitarian aid in the aftermath of disasters. For example, OECD (2007) has estimated that assets valued at over half a trillion dollars in one city (Alexandria in Egypt) alone could suffer damage or be lost because of coastal flooding.

4.6.5. Uncertainty in Assessing the Economic Loss of Extremes and Disasters

Upon reviewing the estimates to date there is a consensus that the state of art of costing climate change related disasters is still preliminary, incomplete and subject to a number of assumptions (Parry et al, 2009; Agrawala and Fankhauser, 2008; Tol, 2005). This is largely due to not only modelling accuracy in climate science and damage estimates, but also in the interaction between adaptation options with future vulnerability and resilience in a specific society.

Climate modeling and future vulnerability. Climate models are not good at reproducing spatially explicit climate extremes yet, due to inadequate (coarse) resolution. Hence projections of extreme events for future climate conditions are highly uncertain and this is often an important hindrance to robustly projecting sudden onset risk, such as flood risk; while drought risks, which are a slower onset phenomena more strongly characterised by mean weather conditions, can better be projected (Christenson, 2003; Kundzewicz et al., 2006).

Apart from climate change, vulnerability and exposure will also change over time, and these aspects of the risk triangle are often not considered equally (see Mechler and Hochrainer, 2010; Hallegatte, 2008). However, important progress is being made in terms of risk based assessments, with the climate change modelling community embracing a more risk-based approach (see, for example, Jones, 2004; Carter et al., 2007). It has also been noted that assessments of climate change impacts and vulnerability have changed in focus from an initial analysis of the problem to the assessment of potential impacts, and finally to the consideration of specific risk management methods (Carter et al., 2007).

*Attribution of economic losses and climatic disasters***.** An important question is to what extent historic losses from disasters can be attributed to anthropogenic climate change. Some studies claim that climate change can be found in records of disaster losses (e.g. Mills, 2005; Höppe and Grimm, 2009; Malmstadt et al., 2009; Schmidt et al., 2009). Others however argue that the role of non-climatic factors (increasing exposure of people and capital) in the observed increase is so large, that any changes in extreme weather incidence cannot be identified (Changnon et al., 2000; Pielke et al., 2005; Bouwer et al., 2007). Also, a particular difficulty encountered in these studies is the attribution of loss changes to anthropogenic climate change. As the incidence of disasters varies with natural climate variability, large variations can be seen in economic losses over decades even without anthropogenic climate change (Pielke and Landsea, 1999; Bouwer, submitted). The attribution of losses to anthropogenic climate change requires long time series, and the analysis needs to take into account natural variability.

A series of scientific studies [references forthcoming] have attempted to detect changes in time series of observed direct losses for particular natural hazards and particular countries or regions, and attribute these changes to both climatic and non-climatic causes. Many of these studies apply a so-called ‘normalization’ procedure (Pielke and Landsea, 1998) to the loss record that accounts for changes in exposure and vulnerability, in order to keep these constant over time (many of these studies have been included in Section 4.6.3.1 above). Typically, these procedures correct the loss record for inflation, population and wealth or capital growth in the disaster affected locations, and show losses from individual events as if they occurred in the same year. This allows observing changes in the weather hazard, rather than the disaster impact.

In general, studies at the local and regional level have found no trend in normalized losses for windstorms (including typhoons and hurricanes; see Section 4.6.3.1). For precipitation related events (intense rainfall, hail and flash floods), the picture is probably more diverse; some studies suggest increase related to a changing incidence in extreme precipitation (Changnon, 2001; Changnon, 2009a; Chang et al., 2009; Fenqing et al., 2005). However, uncertainties in these studies are large as well, given the different normalization procedures, and subtleties in changes in exposure to flooding over time and other non-climatic factors that increase flood frequency that are not always accounted for. The IPCC WG2 Fourth Assessment Report (Wilbanks et al., 2007) discussed a study that has analysed a normalized record of global weather losses. This study did not find sufficient evidence for an economic trend that could be accounted for by anthropogenic climate change (Miller et al, 2008). In conclusion, there is only very limited evidence that anthropogenic climate change has lead to increasing losses; increasing exposure is the main reason for long term changes in economic losses.

With specific reference to river flooding, there is considerable evidence, mostly from the insurance and reinsurance industry (e.g. ABI, 2005), that the economic losses from flood events have generally increased over time (although not everywhere: Miller et al., 2008). However, this trend can be explained almost entirely by changes in socio-economic drivers of flood loss, including increased occupation of flood-prone areas and the increasing value of assets exposed to flood. Pielke and Downton (2000) examined US national flood damage data over the period 1932-1997, normalising trends for increasing population and GDP, and found no evidence of trend. Barredo (2009) examined normalised flood loss data from major European floods, again finding no trend. Data on flood losses are, however, unreliable – particularly for individual, small events (Downton et al., 2005) – and losses from the multitude of small events are probably underestimated. Several authors (e.g. Downton et al., 2005; Merz et al., 2010) call for improved data collection in order to clarify the extent of trends in flood loss.

4.6.6. Comment on the Likely Impact on the Global Loss Figure of a 4°C Rise

Over the last few years, a substantial literature has emerged that has projected potential disaster losses under future climate change. A range of approaches have been utilised, including economic modelling (usually CGE modelling), which include economic impacts beyond the direct damages. Approaches that combine climate models with catastrophe models are more detailed in describing physical processes, but are more limited with regard to cost categories (see also the discussion in Section 4.6.1.1). Also, a number of studies have used simplified approaches for future hazard loss estimation that include simple factor changes in hazards instead of full climate scenarios. In general, few studies have specifically applied a scenario of the impact of a global average 4°C warming. Also, most studies address regional impacts, rather than global aggregate impacts.

Some 4 degree studies are not focused on extremes but rather on slower onset changes in average climate. For example, drought is one of the most serious hazards for Africa's agricultural sector in certain areas. Based on business-as-usual A2 scenario, PACJA predicts with PAGE model that the annual economic costs of climate change in Africa with a 4°C mean temperature rise could be equivalent to 10 per cent of GDP (PACJA, 2009). By 2100, regions of arid and semi-arid land are expected to expand by 5-8 per cent, or 60-90 million hectares, resulting in agricultural losses of between 0.4-7 per cent of GDP in northern, western central and southern Africa (IPCC, 2007).

Agriculture: 4°C rise is predicted to cause a decrease in crop productivity for all cereals (IPCC WGII, 2007) and could result in a net revenue losses of US$95.7/ha in Africa (Nkomo et al., 2007). Take Kenya as an example, losses for mangoes, cashews and coconuts could reach US$472.8 million (Republic of Kenya 2002, in Stern 2006).

Health: Weather based disasters have been described as a significant and emerging threat to public health, particularly in developing countries where it can cause increased morbidity and mortality from common vector-borne diseases such as malaria and dengue, as well as other major killers such as malnutrition and diarrhoea. Climate change is already contributing to the global burden of disease, and this contribution is expected to grow in the future (WHO, 2008). A 4°C rise would see an increasing burden from malnutrition, diarrhoea, cardio-respiratory and infectious diseases, as well increased morbidity and mortality from heat waves, flooding and droughts. It is estimated that by 2080s more than 128 million people would be at risk from hunger (PACJA, 2009). Under a scenario assuming emissions reductions resulting in stabilization at 750 ppm CO2 equivalent in 2210, it is estimated that the climate change attributed cases of diarrhoeal disease, malnutrition and malaria in 2030 would increase by 3%, 10% and 5% respectively comparing with the current cases. The total costs of treatment were estimated to be $4 to 12 billion (Ebi, 2008). This is almost as much as current total annual overseas development assistance for health.

Some studies predicted the future risk from weather disasters. Below a number of studies are discussed, that translated changes in projected hazard frequency and intensity into economic losses.

Tropical storms: The projections of losses from tropical storms largely depend on a) estimated change in frequency and/or intensity of hurricanes due to global warming; and b) the estimated statistical relationship between maximum wind speed and losses. Some studies use high projections in cyclone activity and a high loss response, and therefore project substantial changes of between a 30 and 60% increase in losses by 2040 for different regions, including the Atlantic, Caribbean, and Asia (ABI, 2005a; ABI, 2005b; Narita, 2009; Nordhaus, 2010). Others however estimate these changes to be substantially smaller, in the order of 10-20% increase by 2040 (Hallegatte, 2007; ABI, 2009; Schmidt et al., 2009). In a recent study, Bender et al. (2010) use a series of GCM ensembles, and estimate hurricane losses to increase some 30% by the end of this century, with ranges between -50 and +70%. Pielke (2007) tested extreme cases, and arrived at what can be considered upper end estimates of 50-1350% increases by 2040.

Extra-tropical storms: The projections of losses from mid- and high-latitude extra-tropical storms has been generally approached by combining wind fields of GCMs with damage models (Leckebusch et al., 2007; ABI, 2005a; ABI, 2009; Schwiertz et al., in press). Most studies have been done for Europe or European countries including UK, France, Germany and Netherlands. These studies find moderate impacts (compared to extra-tropical cyclone losses) from climate change of between 10 and 20% increases by 2040 (Leckebusch et al., 2007; ABI, 2005a; ABI, 2005b; ABI, 2009; Narita et al., 2010; Schwiertz et al., in press), except for Dorland et al. (1999) who applied relatively large increases in projected wind speeds for The Netherlands. The study by Narita et al. (2010) has applied an economic model, rather than a GCM approach, but arrives at similar estimates, and results are for worldwide extra-tropical storm losses.

Floods: Many studies have addressed future economic losses from river floods, most of which are focused on Europe, including the UK (Hall et al., 2003; Hall et al., 2005; ABI, 2009), Spain (Feyen et al., 2009), and Netherlands (Bouwer et al., 2010). Feyen et al. (2009) project loss increases for a range of European countries. Schreider et al. (2000) find substantial increases in future losses due to flash floods in Australia. Maaskant et al. (2009) is one of the few studies that projects loss of life from flooding, and projects up to a fourfold increase in potential flood victims in the Netherlands by the year 2040, when population growth is accounted for.

Other weather extremes: Some studies have addressed economic losses from small-scale weather extremes. These include hail damage, for which mixed results are found: McMaster (1999) and Niall and Walsh (2005) found no significant effect on hailstorm losses for Australia, while Botzen et al. (2010) find a significant increase (up to 200% by 2050) for damages in the agricultural sector in the Netherlands, although the approaches used vary considerably. Rosenzweig et al. (2002) report on a possible doubling of losses to crops due to excess soil moisture caused by more intense rainfall. Hoes (2007), Hoes and Schuurmans (2006), and Hoes et al. (2005) estimated increases in damages due to extreme rainfall in the Netherlands of some 30% by 2040.

Role of factors other than climate change: It is well known that the frequency of weather hazards is only one factor that affects total risks, as changes in population, exposure of people and assets, and vulnerability determine loss potentials. But few studies have addressed these factors. However, the ones that do generally underline the important role of projected changes (increases) in population and capital at risk. Some studies indicate that the expected changes in exposure are much larger than the effects of climate change, which is particularly true for tropical and extra-tropical storms (Pielke et al., 2007; Feyen et al., 2009; Schmidt et al. 2009b). Other studies show that the effect of increasing exposure is about as large as the effect of climate change (Hall et al., 2003; Maaskant et al., 2009; Bouwer et al., 2010), or estimate that these are generally smaller (Dorland et al. 1999; Hoes, 2007). Finally, many studies underline that both factors need to be taken into account, as the factors do in fact amplify each other, and therefore need to be studied jointly when expected losses from climate change are concerned (Hall et al., 2003; Bouwer et al., 2007; Pielke, 2007; Feyen et al., 2009; Bouwer et al., 2010).

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Case Study – Darfur Conflicts and the Role of Climate Change

Is the conflict in Darfur the first climate change war? asked economist and *Scientific American* columnist Jeffrey Sachs at an event at Columbia University in 2007 (Sachs, 2008). “Don’t doubt for a moment that places like Darfur are ecological disasters first and political disasters second.”

But new research would suggest the answer to Sachs's question is no, at least regarding the novelty of Darfur. Agricultural economist Marshall Burke of the University of California, Berkeley and his colleagues have analyzed the history of conflict in sub-Saharan Africa between 1980 and 2002 in a new paper (Burke *et al.*, 2009).

"We find that civil wars were much more likely to happen in warmer-than-average years, with one degree Celsius warmer temperatures in a given year associated with a 50 percent higher likelihood of conflict in that year," Burke says (see also Biello, 2008). The implication: because average temperatures may warm by at least one degree C by 2030, "climate change could increase the incidences of African civil war by 55 percent by 2030, and this could result in about 390,000 additional battle deaths if future wars are as deadly as recent wars."

In fact, temperature change offered a better prediction of impending conflict in the 40 countries surveyed than even changes in rainfall (Sachs, 2006), despite the fact that agriculture in this region is largely dependent on such precipitation. Burke and his fellow authors argue that this could be because many staple crops in the region are vulnerable to reduced yields with temperature changes—10 to 30 percent drops per degree C of warming.

"If temperature rises, crop yields decline and rural incomes fall, and the disadvantaged rural population becomes more likely to take up arms," Burke says. "Fighting for something to eat beats starving in their fields."

Whereas 23 years in 40 countries provides a relatively large data set, it does not exclude other possible explanations, such as violent crime increasing with temperature rise, a drop in farm labor productivity or population growth. "Fast population growth could create resource shortage problems, as well," notes geographer David Zhang of the University of Hong Kong, who previously analyzed world history back to A.D. 1400 to find linkages between war and temperature change (Zhang *et al.*, 2007). But "the driver for this linkage," Zhang says," is resource shortage, mainly agricultural production, which is caused by climate change."

Burke and his colleagues specifically excluded records from prior to 1980, because of the conflict rampant in the wake of Africa's emerging colonial independence after World War II. "A lag of a couple of decades would leave sufficient time for post-independence turmoil to wear out," Burke argues. "We took the approach that the best analogue to the next few decades were the last few decades."

Proving the link—and providing a specific mechanism for the increase in conflict, whether agricultural productivity or otherwise—remains the next challenge. "I believe that the historical experience of human society of climate change would provide us [with] the evidence of how climate cooling and warming during the last thousand years created human crisis, and also the lessons for human adaptive choices for climate change," Zhang notes.

"We feel that we have very clearly shown the strong link between temperature increases and conflict risk," Burke adds. But "what interventions will make climate-induced conflict less likely?

The U.S. military, for its part, is concerned about the issue, analyzing the possibility for climate change to destabilize countries in recent reports, such as an essay from members of the CNA Military Advisory Board in November, "Climate and Energy the Dominant Challenges of the 21st Century" (Wald, Goodman and Catarious, 2009).

In April 2007, 55 delegations to the UN met at the Security Council to discuss the security implications of climate change. Led by the then UK Foreign Secretary, Margaret Beckett, states shared their concerns about the security implications of climate change. UN Secretary General Ban Ki-moon talked of scarce resources, fragile ecosystems and severe strains placed on the coping mechanisms of groups and individuals, potentially leading to "a breakdown of established codes of conduct, and even outright conflict.

A decline in water supplies for drinking and irrigation, a decline in agricultural productivity as a result of changes in rainfall, temperature and pest patterns, and large economic and human losses attributable to extreme weather events will all take their toll on the global system as a whole.

Some western governments are concerned that these conditions will create an unstable world and may lead to a subsequent rise in terrorist activity. What is more likely, I argue, is a potential rise in conflict in the most environmentally and politically vulnerable states. International Alert, a peace-building organisation, has identified 61 countries they perceive as being at risk from the ‘double-headed' risk of climate change and conflict (Smith, 2007).

This article will specifically examine the potential rise in three types of conflict as a result of climate change:

- Political violence
- Inter-communal violence
- Interstate warfare

This article does not argue that climate change will directly cause conflict in the future. It argues that the environment (as a result of climate change) will become a more prominent factor in the outbreak of conflict.

Changes in the environment alone will not result in conflict. They need to be combined with existing divisions within society, be they ethnic, nationalist or religious. As Idean Salehyan (Salehyan, 2007) argues, there is much more to armed conflict than resource scarcity and natural disasters. However, that doesn't mean that resources and changes in the environment should be excluded as potential factors in the outbreak of conflict.

Political Violence

An April 2007 report by the Military Advisory Board of the CNA Corporation, a US-based think tank, seeks to make explicit the link between climate change and terrorism. In the report, retired Admiral T. Joseph Lopez states that "climate change will provide the conditions that will extend the war on terror" (CNA Corporation, 2007). This statement is based on the premise that greater poverty, increased forced migration and higher unemployment will create conditions ripe for extremists and terrorists (CNA Corporation, 2007). Although there is a well-established link between economic disadvantage and civil unrest, this does not necessarily manifest itself through terrorism.

The likelihood of increased terrorism

There are a number of reasons why it is unlikely that climate change will lead to an increase in terrorist activity, at least in the short-term. Firstly, terrorism tends to be a response to a perceived and visible injustice committed by a tangible group or government against a particular group of people. In addition, individuals or groups tend to resort to violence if other avenues are unavailable or perceived as not working.

Environmental change will be difficult to attribute to a specific group of people or a state, and the changes will take place over such a timescale that they won't be instantly visible. This may not stop organisations and states from being targeted, however those involved may merely want to bring attention to issues, knowing that they will not be able to solve the problem through violent action.

Secondly, varied and diverse aims of groups affected by climate change make organised international terrorism as a response to climate change is highly unlikely. The actions of a group in the Middle East campaigning for access to water will be unlikely to improve the situation for those suffering severe flooding in Asia. If terrorism and civil unrest do occur they are likely to be on a local, perhaps regional scale.

Instead of focussing on environmental groups and tightening anti-terrorist laws, governments should be focussing on ways to both curb and mitigate the effects of climate change. Their attention should also turn to less developed countries, who stand to suffer the worst of climate change and who lack the capacity to be able to respond effectively. Climate change in less developed countries is not likely to lead to terrorism, but to conflict.

Inter-Communal Conflict

At the most basic level, we all depend on the natural environment for our survival. It is the sole provider of the most basic of human needs: food, water and shelter. Global warming and the resulting changes in the environment will affect our ability to meet these needs. Conflict as a result of climate change is likely to emerge if a) the carrying capacity of the land is overwhelmed, or b) as a result of competition over specific resources.

Carrying capacity

Carrying capacity is defined as the maximum number of people an area can support without deterioration. Climate change will alter the carrying capacity of many vulnerable areas of the world either as a result of land degradation (flooding, drought and soil erosion) or the pressures of migration. "If there is a choice between starving and raiding, humans raid," according to Harvard archaeologist Dr. Steven LeBlanc. The most combative societies are therefore often the ones that survive.

Many climate change scientists predict that there will be a "significant drop in the carrying capacity of the Earth's environment" which could potentially lead to the sort of Hobbesian state which LeBlanc describes.

There is already growing evidence to support the theory that the current conflict in Darfur is partly due to land degradation as a result of climate change. Less than a generation ago, Africans and Arabs lived peacefully and productively in Darfur. More recently, desertification and increasingly regular drought cycles have diminished the availability of water and arable land, which has in turn, led to repeated clashes between pastoralists and farmers.

Dr. John Reid, then British Defence Secretary, speaking in March 2006 stated that "the blunt truth is that the lack of water and agricultural land is a significant contributory factor to the tragic conflict we see unfolding in Darfur."

Rainfall has declined by up to 30% in the last 40 years and the Sahara is currently advancing at over a mile per year. The potential for conflict over disappearing pasture and evaporating water holes is huge. The southern Nuba tribe have warned they could restart the half-century war between North and South Sudan because Arab nomads (pushed into their territory by drought) are cutting down trees to feed their camels.

Migration

Environmental-related migration between and within states may increase existing tensions and/or create new ones, potentially leading to conflict. This issue will primarily affect underdeveloped states as weak infrastructure, resource scarcity and income disparity increase the risk of migration-related conflict. Poverty and resource scarcity are exacerbated by an influx of immigrants, especially if environmental migrants worse existing tensions and divisions within society (ethnic, national or religious).

However, conflict will only occur if the receiving area is unable to deal with the migrants.

Interstate Warfare

Environmental-based conflict can also erupt as a result of competition over an abundance of a commercially valuable resource located in a particular area. Resources are not distributed evenly and do not follow internal or external boundaries and resource-based conflict can happen between states as well as within them.

Conflict over resources is not confined to oil, however. ‘Water wars’ are set to increase as water levels decline and rapidly growing populations place increasing pressure on water supplies.

Forewarned is forearmed

This article paints a grim picture of disputes over precious resources, the erosion of fragile ecosystems and a world dominated by conflict. The real question to ask is not how likely is this to happen, but what can we do to prevent it happening and how can we mitigate the effects.

Margaret Beckett, then UK Foreign Secretary, argued in a speech at the Royal United Services Institute that in the world of military security, planners prepare for the worst-case scenario; they don't wait to see what might happen. The same approach is required for climate change. Preparing for the security implications of climate change means both acting to make these events less likely and also strengthening state capacity to deal with the effects.

This doesn't mean (as some analysts have suggested) adopting a ‘fortress mentality', shoring up our borders and increasing our defensive capacity, but instead focusing on ways in which resources can be effectively managed and distributed.

We also need to ensure that the socio-economic resilience of those states most vulnerable to the direct effects of climate change is strengthened and that the global system as a whole is prepared for potentially huge global changes. The meeting at the UN held in April was a step in the right direction. Climate change needs to be permanently placed on the UN's agenda. Many states in attendance were in support of the Security Council addressing the issues, citing Resolution 1625, concerned with the prevention of armed conflict, in support of the meeting.

Many more states, particularly the powerful and developed nations, need to be convinced of the importance of the issue and to act on climate change before it creates global conflict. The irony of climate change is that although the more developed states are the main polluters, less developed states will suffer most and have the least capacity to respond effectively to climate change. Many already suffer from poverty, resource scarcity, health crises and ethnic/religious/national tensions and are dependent on the natural environment. These factors make them more prone to conflict as a result of climate change and lessen their ability to adapt to environmental change.

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Table 4-1: Sidr versus Nargis: general figures

Characteristics	**Sidr 2007 (Bangladesh)**	**Nargis 2008 (Myanmar)**
Date of landfall	15 November 2007	2 May 2008
Tropical cyclone max. category	5	4
Tropical cyclone max. category on land	4	3
Maximum windspeed	245 Km/h (68 ms^{-1})	235 (> 65 ms^{-1})
Storm surges height	5 – 6 m	4
Total population exposed (PREVIEW)	10,562,200	8,465,300
Cyclone duration		?
Total GDP exposed	?	2,147,500,000
Total Affected (EM-Dat)	8,978,541	2,420,000
Killed	4,234	138,366
Estimated damages (in millions US$)	2300[*] (1.7 billion)[**]	4000
Shelters at time of the cyclones	3976	?
Number of people evacuated	3.2 millions	?
Percentage of people aware of cyclone prior to landfall	86%	?
Volunteers for warning	43,000	?

Compiled from CRED 2009, Paul 2009, Webster 2008 **[missing some values: to be completed]**

Table 4-2: Factors to be considered in this section.

Hazard	**sector and system**	**region**
heatwave	freshwater resources	Africa
coldwave?	terrestial and inland water systems	Europe
flood due to heavvy rain	coastal systems and low-lying areas	Asia
GLOFs	ocean systems	Australia
drought due to dry weather	food production systems and food security	North America
ENSO	urban areas	Central and South America
bush/forest fire	rural areas	Polar regions
landslide following heavy rain	key econoimc sectors and servicies	Small islands
cyclone(strong wind&rain)	human health	Open oceans
cryosphere	human security	
sea level rise	livelihoods and poverty	

Table 4-3: Yearly average human exposure to tropical cyclones in 1970.

Tropical Cyclones	**1970**				
Region	**Cat1**	**Cat2**	**Cat3**	**Cat4**	**Cat5**
Africa	665311	234786	84404	2983	0
Asia + Pacific	30018234	6730459	2581252	295333	26308
Europe	147154	34598	847	0	0
Latin America + Caribbean	999431	369094	206353	126451.	36755
North America	1795531	385926	268477	42066	0

Source: Peduzzi *et al.*, 2009

Table 4-4: Yearly average human exposure to tropical cyclones in 1990

Tropical Cyclones	**1990**				
Region	**Cat1**	**Cat2**	**Cat3**	**Cat4**	**Cat5**
Africa	1053320	383620	137256	5137	0
Asia + Pacific	41555940	9235975	3535603	413795	39093
Europe	157026	36568	1002	0	0
Latin America + Caribbean	1392138	511176	279134	186204	58611
North America	2187398	470306	327031	51309	0

Source: Peduzzi *et al.*, 2009

Table 4-5: Yearly average human exposure to tropical cyclones in 2010

Tropical Cyclones	**2010**				
Region	**Cat1**	**Cat2**	**Cat3**	**Cat4**	**Cat5**
Africa	1769951	654177	232848	9181	0
Asia + Pacific	51161149	11327859	4347756	516308	51057
Europe	173870	40789	1081	0	0
Latin America + Caribbean	1722069	629207	341603	244147	81042
North America	2724747	585767	407402	63885	0

Sources: Peduzzi *et al.*, 2009

Table 4-6: Yearly average human exposure to floods in 1970, 1990 and 2010

Regions	HE_1970	HE_1990	HE_2010
Africa	588'019	1'009'604	1'658'154
Asia + Pacific	23'436'375	36'930'541	51'216'040
Europe	954'525	1'083'212	1'095'893
Latin America + Caribbean	554'997	852'419	1'148'162
North America	297'546	363'949	452'645
West Asia	20'631	38'975	68'375
Total human exposed	25'852'092	40'278'701	55'639'268

Source: Peduzzi *et al.*, 2009

Table 4-7: Coastal systems: summary table of observed and predicted exposure trends

Coastal systems	Current exposure	RSLR	Storm surges	Storm waves	Extreme rainfall	Sediment supply changes
Beaches	X	XX	XX	XX	-	XX (if negative)
(Soft) seacliffs	X	XX	XX	XX	XX	-
Deltas	X	XX	XX	XX	xx	XX (if negative)
Estuaries	X	XX	XX	xx	thr	XX
Saltmarshes	X	thr	o	XX	-	thr
Mangroves	X	XX	xx	xx	-	xx (if negative)
Coral reefs	X	-	-	XX	XX	XX (if positive)
Seagrasses	x	-	-	-	xx	-

Key: X large exposure; x, moderate exposure; XX, large change in predicted exposure; xx, moderate change in predicted exposure; -, small or not established change in predicted exposure; thr, future exposure depends on thresholds; o, future exposure depends on many other environmental parameters; RSLR, Relative sea level rise. Note: The predicted effects on coral reef exposure are based only on sea level rise considerations and not on potential increases in seawater temperatures.

Table 4-8: Current and future population exposure in low elevation coastal zones

Region	**Area** $(10^3 km^2)$	**Population expos. (current)** (millions)	**Population expos. (2050 no tipping)** (millions)	**Population expos. (2050 with tipping)** (millions)
Africa	191 (1)[1]	2.80	3.76 (34%) [2]	5.77 (106%)[2]
Asia	881 (3)	47.76	60.15 (26%)	82.68 (73%)
Europe	490 (2)	9.56	11.70 (22%)	16.42 (72%)
Latin America	397 (2)	4.60	5.57 (21%)	7.45 (62%)
N. America	553 (3)	4.82	6.25 (30%)	8.88 (84%)
Oceania	131 (2)	2.00	2.26 (26%)	2.68 (49%)
SIS	58 (16)	n/a	n/a	n/a
Total	**2700 (2)**	**71.35**	**89.70 (26%)**	**123.87 (74%)**

Low Elevation coastal areas (LECZ) (McGranahan et al., 2007), current and future (2050) population exposure to inundation in the case of the 1-in-100-yr extreme storm under 'normal projections' (SLR of 0.15 m) and 'tipping projections' (SLR 0.50 m, due to the partial melting of the Greenland Ice Sheet (GIS) and West Antarctic Ice Sheets (WAIS) (Lenton et al., 2009). The numbers in parentheses refer to: [1], percentage of total land area; [2], increase (%) in exposure relative to population presently exposed. Note: Projections refer to current population i.e. not accounting for population growth by 2050. Key: SIS, Small Island States.

Table 4-9: Trend of water-related disasters from 1980 to 2006 by hazards (based on Adikari and Yoshitani (2009))

Total/General	Increase in every region. Linear increase more than double in Asia and more than four-fold in Africa.	Decreasing trend with occasional peaks.	In general, the estimated water-related economic losses globally show an increasing trend. The trend had a trough during the period 2001 to 2003, and then increased sharply until 2006. The increase was due to the huge economic damage caused by Hurricane Katrina in the United States in 2005. Among water-related disasters, windstorms, floods and droughts are the main contributors to economic losses – in descending order – and the rest of the water-related disasters are insignificant but underestimated. The estimates of economic losses caused by water related disasters in different parts of the world may not be entirely reliable, because the values obtained from different countries are derived under different definitions and using different estimation methods, monetary units and purchasing power. Furthermore, some countries do not carry out surveys or keep proper records, while others may keep their records confidential. Reported figures may not be accurate and are sometimes even exaggerated to attract media attention.
Floods	Increase in every region. Increase to more than trebled in Asia and to more than four-fold in Africa.	No particular regional trend except in Africa, where the numbers increased steadily.	
Windstorms	Increase in every region except for a trough during the period from 1995 to 1997 in Asia	No distinct trend,	
Slides	No distinct trends in any region except in Asia, where they increased more than four-fold.	Increase in Asia with a peak in the period 1995 to 1997. Steady decrease from 1988 in the Americas with a sharp increase in the early 1980s. In Europe, increase in the early 1980s, remained steady till the late 1990s, and then decreased.	
Droughts	No clear trend. In Africa, where droughts are prominent, droughts decreased in the period from 1992 to 1994, then increased again.	In Africa, increase till 1985, decrease till 1997, then increase again. In Asia, increase till 1991 and then sudden decline. More than 99% of the fatalities globally were reported in Africa.	
Water-borne epidemic diseases	Increasing trend, especially from the mid 1990s. Globally, the number of epidemics was at its highest in the period from 1998 to 2000, which is thought to be influenced by the African and Asian regional peaks.	Decrease in Asia but remained steady in Africa. Highest in the 1990s, when Africa, Asia and the Americas were all hit hard by epidemis. Since then decline in all three regions.	

Table 4-10: Risk, glacier outburst floods and management

PREVENTION		MANAGEMENT/MITIGATION		ADAPTATION
Risk identification	Flood Prevention	Property	Population	
Glacier lake inventory	Remote sensing of glaciers	Controlling lake drainage and dam stability	Developing a regional and local action plan	Re-locating hydropower facilities in non-threatened valleys
Identification of glaciers with history of GLOFs	Monitoring of glaciers and lakes	Reinforce natural dam or construction of artificial dam	Public Awareness and Education	Relocation of rural and urban settlements
GLOF hazard classification (probability of occurrence and magnitude)	Monitoring dam stability (ice or moraine)	Structural measures along channels	Evacuation plans/civil defence	Re-assessment of development projects
GLOF hydraulic modelling (hydrograph routing, sediment load)	Monitoring of triggering factors: temperature, glacial melting and calving instabilities, rock falls onto lakes, etc	Structures for lake water use	Health and safety regulations	
Hazard mapping and assessment of vulnerability of critical assets	Early warning system to villagers and managers of sensible infrastructure	Economic impact assessment (vulnerability and exposition)	Social impact assessment (vulnerability and exposition)	

Table 4-11: Links between sectors, exposure, vulnerability and impacts

Affected System/Sector	**Region [Resolution]**	**Examined period**	**Vulnerability (State of susceptibility and coping capacity)**	**Hazards/exposures and their extent**	**Impacts / Risks**	**Particularly severely affected groups (if exist)**	**Descripter of literature / Expected impacts**	**Reference(s)**
Food	Worldwide	-	-	Temperature	Impacts on crop production	-	Summary of effects of high temperature stresses on growth and development of various crops.	Hatfield et al. (2008)
Food	US, Japan	-	-	Temperature	Impacts on rice production	-	Summary of effects of high temperature stresss on growth and dvelopment of rice with a note on some threshold temperatures.	Kim et al. (1996); Prasad et al. (2006)
Food	Worldwide	-	-	Temperature	Impacts on maize production	-	Summary of effects of high temperature stresss on growth and dvelopment of maize with a note on some threshold temperatures.	Ben-Asher et al(2008); Fonseca and Westgate (2005)
Food	Whole Japan [4 sub-national regions]	Present (1981-2000), 2046-2065 and 2081-2100	Different levels of adaptation regarding planting date shift and heat tolerant variavirity use were assumed.	Temperature (daily maximum and minimum) , radiation, CO2 concentration	Rice yield (mean and inter-annual variability)	Tokai, Chubu, Kansai regions (Intensification of heat in summer is projected, which will cause decrease in and amplified inter-annual variability of rice yield)	Impact of climate change on rice yield in Japan was evaluated using the PRYSBI model, which explicitly simulates sterility and growth limitation due to extremely high and low temperature during yield formation period.	Yokozawa et al. (2009)
Food	Whole Japan (9 sub-national regions)	Present (1991-1999), 2071-2079	Change in standard rice yield (used for calculating insurance payouts) was permitted along with the change in rice yield.	Temperature (daily maximum and minimum) , daily total solar radiation, hourly maximum precipitation, hourly maximum wind velocity, and atmospheric CO2 concentration.	Rice insurance payouts (billion Japanese yen)	In Kanto-Tozan, Hokuriku, Kinki regions, the increase of 11-19% in rice insurance payouts is projected due to yield loss associated with heat stress.	Preliminary assessment of climate change impact on the rice insurance payout in Japan. Reflecting regional changes in yield, the rice insurance payout is expected to significantly decrease in northern Japan while it is expected to slightly increase in central and western Japan. In total, the 9-yr mean payout in Japan in the 2070s decreased to 120.2 billion yen (87% of the present payout averaged over 9-yr in the 1990s).	Iizumi et al. (2008)

Food	Andean region (Peru, Bolivia, Equador)	1970- current	-	Glacier retreat	Floods, water shortage (drought). GLOF, landslides.	Populations living in valleys depending from water from glaciers	With glaciers retreating due to global warming and El Niño episodes, the Andean region faces increasing threat on water supply. With most of the precipitation coming in 3-4 months, the glaciers plays a temporal buffer by stocking precipitations in ice and snow and redistribution of the water by melting during the dry season. The glaciers recession reduces the buffering role of the glaciers, hence inducing a double threat: more floods during raining season and more water shortage during the dry season. Physically, the glaciers are holding rocks and other debris. With retreating of glaciers, such debris are now exposed and could lead to debris flows after heavy rainfalls or after earthquakes. The recession of the glaciers also induces the formation of high altitude lakes and some of them include a risk of being suddenly released after earthquakes, of if an avalanche creates a GLOF. The risk of collapse of such dams can have drastic consequences.	Silverio and Jaquet (2005); Vuille et al. (2008); Zemp (2008)

Food	Global(Sub-national examples)	Now - near term future	The majority of households produce maize in many African countries, but only a modest proportion sell it – the great majority eat all they produce. In Kenya for example, nearly all households grow maize, but only 36% sell it, with 20% accounting for the majority of sales. This pattern sees a growing inequality of income which is likely to continue as farms get smaller due to population growth and environmental degradation (FAO, 2009). Both such famers and their governments have limited capacity for recovery (Easterling, W & Apps, M, 2005). Farmers do not usually have insurance although micro insurance is increasingly available.	Drought, floods, and cyclones are the main hazards faced by subsistence farmers. Rainfall pattern is also important. The economies of many developing countries rely heavily on agriculture; dominated by small-scale and subsistence farming. People's livelihoods in this sector are especially exposed to weather extremes (Easterling, W & Apps, M, 2005).	Food shortage and loss of cash livelihood due to crop failureCrop price increaseDegradation of food security	Subsistence farmers who have a marginal existence under normal conditions, are probably the most severely impacted by climate and weather events. The most vulnerable to food price increases are poor, urban residents in food-importing developing countries; the landless poor and female-headed households are also particularly vulnerable (FAO 2008). (Global food price increases are burdened disproportionally by low-income countries, where many people spend up to 50% of their income on food (OECD-FAO 2008)). In some locations women and girls bear the initial brunt of food scarcity, which is both a result of, and contributes to, systemic gender inequality (Vincent et al 2008).	The initial obvious impact is a shortage of food for those entirely dependent on their own produce for their food supply, and those whose cash livelihood depends on their own food crops. Crop-failure is a key driver for rural-urban migration, which is expected to be exacerbated under climate change. For example: Since 1970 Malawi has been facing increasing frequency and severity of drought and flood events, less seasonal rain and higher temperatures. A hybrid drought tolerant maize variety has been promoted, but requires expensive inputs such as chemical fertiliser, which is unaffordable for small holder farmers unable to find cash employment. These factors come together to create significant hardship for smallholder farmers (ActionAid, 2006). A more complex impact followed Cyclone Nargis in the Ayeyarwaddy delta region of Myanmar. The disaster's convergence with the global financial crisis has seen the rural economy collapse as credit has been withdrawn. Food security is again a significant concern (Stone, 2009). The factors influencing the recent price increases are in many ways a mirror to the challenges global food security will face in the next century under climate change. (Nelson et al (2009) Due to changes in marine ecosystems, populations will not be able to supplement their diet with fish, which is the primary source of protein for more than one billion people in Asia. Changes in rainfall patterns may disrupt major river systems used for irrigation. Rising sea levels could swamp fertile coastal land, rendering it useless. These impacts will be in conjunction with an increase in the frequency and severity of extreme weather events (Garnaut 2008).	ActionAid (2006); CGIAR (2002); Easterling and Apps (2005); Fischer et al (2005); FAO (2008); FAO (2009); Garnaut (2008); Nelson et al (2009) ; OECD-FAO (2008); Stone (2009)

Food	China	2000-2007	Less awareness and inadequte measures for the increasing climatic risks	Flood, Drought	Affected crop area	Northern China (drought); Yangtz and Huai river basins (flood)	25% loss of total annual crop production accounted for the flooding risk in China. Flooding disasters would have an increasing frequency and severity in future, especially in the major crop areas of Yangtz River basin and Huai Riverbasin. Northern China suffered from an expanding drought areas in recent 50 years (60% of annual average disaster-related crop loss caused by drought), and the trend would be worse in the next decade as well.	Commission for China's Climate Change Scientific Report
Food	China	2050	-	Temperature	Impacts on crop production	Middle and West of China.	China's total production of three major crops would reduce 5-10% at an average rate annually. Adaptive measures would lower down the vulnerability of these area.	Wang (2002)
Food	China	Near- mid term future	No adaptation assumed	Temperature	Impacts on crop production		an 2.5°C increase would cause a net decrease of Chinese crop production if without taking any adaptation measures.	Xiongwei et al, (2007)
Health	Lesotho, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe	Present (2001-2003)	High HIV/AIDS prevalence in modern area is causing high sensitivity to drought.	Drought	Child nutritional status (prevalence of underweight)	Better-off (modern) area with more HIV/AIDS	Areas with higher HIV/AIDS showed more deterioration in child nutrition. A significant area-level interaction was found of HIV/AIDS with the drought period, associated with particularly rapid deterioration in nutritional status. It is found that HIV/AIDS amplifies the effect of drought on nutrition, so rapid and effective response will be crucial when drought strikes.	Mason et la. (2005)
Health	North Indian Ocean (Bangladesh and Myanmar)	2007-2008	-	Tropical cyclones	Mortality	Coastal population in Bangladesh and Myanmar	Tropical cyclone Sidr (Bangladesh 2007) and Nargis (Myanmar 2008) are of similar intensity. However, the impacts (in mortality) were drastically different. By comparing these two events, the role of (good) governnance translated in improved early warning systems, preparedness and environment health, which mostly explained why Nargis had 32 times more casualties as compared with Sidr.	Gob (2008); Paul (2009); Webster (2008)
Health	Bangladesh	1991	Shelter	Cyclone	Mortality	Children <10 y.o. and 40+ yaers old females	Mortaliity was greatest among <10 years old children and 40+ years old females. Nearly 22% of persons who did not reach a concrete or brick structure died, whereas all persons who sought refuge in such structures survived.	Bern et al. (1993)
Health	Ethiopia	near past	a lack of flood-specific policy, absennce of risk assessment, and weak institutional capacity	Flood	deaths, injuries and diseases such as malaria and diarrhoea	-		Abaya et al. (2009)
Health	Bangladesh	1998	Lower education level, house with a non-concrete roof, tube-well water, distant water source and unsanitary toilets	Flood	Hospital visits due to diarrhoea (cholera and non-cholera)	Low SES group	In Dhaka, Bangladesh, the severe flood in 1998 caused diarrhea during and after the flood, and the risk of non-cholera diarrhea was higher for those with lower education level and not using tap water	Hashizume et al. (2008)

Health	Gernany	2002		Food	injuries and diarrhoea		In 2002 report, WHO assumed that countries with 6,000+ US dollars of per capita GDP. On the contrary, diarrhea as well as injuries occurred after a 2002 flood in Germany, one of the developed countries	Schnitzler et al. (2007)
Health	Mozambique	2000	Increase in population, food shortage, temporary living conditions, contaminated drinking water	Malaria and diarrhoea	Incidence		It may not always be true, but floods can increase the patients of malaria in some cases. In Mozambique, the incidence of malaria increased by 4 to 5 times after the flood in 2000 (compared with non-disaster periods)	Kondo et al. (2002)
water	China, Yellow Riiver	2030-2050	-		Water supply	Economic sectors	the Yellow River would have an increased annual cost of $ 500 million from 2030s to 2050s with a changing climate.	Kirshen et al. (2005)
Forestry / Ecosystem	The tropical forests of South America, Africa and Asia	1960 - current	-	Forest fires, drought, deforestation	Biodiversity losses, soil erosion, decication, GHG emissions, deforestation		Forest fires are increasing climate change by adding GHG into the atmosphere and by decreasing forest area for carbon sink. In turn, climate change induces more extreme events such as droughts and El Niño. Drought increases carbon emission from tropical forests by increasing forest flammability and tree mortality, and by suppressing tree growth. Droughts make peatlands more vulnerable to fires which contain vast amount of carbon. Drought is a trigger for human ignited forest fires leading to widespread deforestation and carbon emissions.	Field et al.(2009); Van Der Werf et al.(2008); Costa and Pires (2009); D'almeida et al. (2007); Phillips et al. (2009)
Forestry/ Ecosystem	North AmericaSiberia	-2100	-	Temperature	Forest fire (the area affected)		In western part of North America in the recent 30 years the area affected by forest fires increased twofold, and in the coming 100 years under expected warming it will further increase by 80%. Modelling of forest fires in Siberia shows that the temperature rise from 9,80C to 15,30C may result in the fact that a number of years with severe fires will increase twofold, an area affected by forest fires will be increasing by almost 15% per year and timber resources will reduce by 10%.	?
Forestry, tourism, ecosystems	Mediterranean countries (Portugal, Spain, Italy, Greece,…)	1900-2005 (observed) and 2020-2100 modelled	Increase duration of fire season and summer temperatures. Higher coping capacity by improving meteorological prediction, better forest fire fight resources, better knowledge of combustion material	Heat waves, droughts	Forest fires, lightning	Forest farming, tourism, rural settlements	?	?

Forestry / Ecosystem	China	1970-current	-	temperature, others	forest coverage		The economic loss of affected forests areas is more than 80 billion RMB annually since 1970s in China . The harmful insects affected forest is about 6% of total re-forestation in China annualy.	Yan and Cai (2006)
Housing, tourism, biodiversity, transport.	Coastal areas	current- 2100	-	Sea level rise			Coastal areas are among the world's most vulnerable to climate extremes, such as Sea Level Rise (SLR) and other events (e.g. tropical storms and cyclones and related storm surges), the intensity and frequency of which is projected to increase. Moreover, as the size/permanence of coastal communities and infrastructure has increased very significantly over recent decades, affecting the ability of coastal systems to respond effectively to SLR and other extreme climate events, the exposure of coastal communities/assets is growing at an ever increasing rate. The severity of the impacts will depend on the rate of SLR, with rapid SLR likely to impact more severely natural systems and amplify the potential economic losses/costs of adaptation. Coastal landforms (beaches, seacliffs, estuaries, lagoons, deltas) are highly likely to suffer increased rates of erosion, while coastal ecosystems, such as coastal wetlands, coral reefs and seagrasses may also be severely affected. Economic activities in coastal areas that may be at threat from SLR and other extreme events include among others transportation (ports and other coastal infrastructure, e.g. airports, railways and roads) and tourism (due to beach erosion and threat to coastal tourism infrastructure). Small island states, particularly SIDS, are likely to be very severely affected; in some cases, and depending on the SLR scenarios, there might even be a need for permanent population evacuation. In some coastal settings and landforms (e.g. deltas and coastal wetlands), SLR will be further exacerbated by (i) land subsidence triggered by natural processes (e.g. sediment auto-compaction) and/or human-induced interference (e.g. extraction of groundwater/hydrocarbons); (ii) diminishing sediment supply due e.g. to river damming and other management schemes.	The Copenhagen Diagnosis (2009); Lenton et al(2009); Cai et al.(2009); Ericson et al. (2006); Woodroffe (2008)
Settlements	Russian arctic		-	Permafrost degradation	Damage on foundations of buildings Disruption of operation of vital infrastructure in human settlements		Climate warming leads to permafrost degradation, the 40-80-cm increase in seasonal soil thawing depth and the northward shift of the isotherm that characterizes a southern boundary of insular permafrost [Sherstyukov, 2009]. Changes in permafrost damage the foundations of buildings and disrupt the operation of vital infrastructure in human settlements, resulting in an additional risk of disease. Total area of permafrost may shrink by 10-12% in 20-25 years, with permafrost	Sherstyukov (2009); Anisimov et al. (2004)

							borders moving 150-200 km northeast [Anisimov et al., 2004].	
Infrastructure / Settlements	Whole Japan [1kmx1km]	Present (1970-2000), Around 2050	Exposed economic value is estimated for each grid with using spatial land-use data and unit values of the land-use classes.Assuming the status quo for future.	Landslide exacerbated by increasing intensity of precipitation.Exposed economic value of each grid cell is assumed not to change (the status quo).	Economic loss due to landslide	Area with high expected economic loss due to landslide concentrate in some prefectures (Tochigi, Gumma, Saitama, Toyama, Ishikawa, Fukui, Hiroshima, Kagoshima).	Slope failure risk is expected to increase in future at many places, since increase in frequency/intensity of strong rainfall is projected by climate models. Slope failure risk in Japan under the changed precipitation was evaluated for the period around 2050 with spatial resolution of 1km^2. With using spatial data on daily precipitation, geography, geology, and landuse, slope failure probability in each grid cell was calculated first. Then, with multiplying economic value of each grid cell, expected economic loss due to slope failure (return period: 50 years) under the changed climate condition was calculated. For creating daily precipitation sceario in future, climate projections of MIROC3.2-hires (AO-GCM with 1.125x1.125 resolution) and MRI-RCM20 Ver.2 (Dynamical downscaling using RCM with 20kmx20km resolution) were employed. Grid cells with high slope failure risk is expected to distribute from the top to the skirts of mountainious area. Especially, in the south Hokkaido region, the coast of Japan Sea from Hokuriku region to Chugoku region, and median tectonic zone from Tokai region through Shikoku region, incrase in slope failure risk is most significant. In some prefectures (Tochigi, Gumma, Saitama, Toyaam, Ishikawa, Fukui, Hiroshima, and Kagoshima), area with high expected economic loss due to slope failure concentrates. Therefore, prioritized implementation of adaptation measures will be needed in those prefectures.	Kawagoe and Kazama (2009)

Settlements/other	Global	Current – short term	Most urban centres in sub-Saharan Africa and in Asia have no sewers (Hardoy, Mitlin and Satterthwaite, 2001). Sanitation infrastructure is the main determinant of the contamination of urban floodwater with faecal material, presenting a substantial threat of enteric disease (Ahern et al., 2005). In Andhra Pradesh, India, a heat wave killed more than 1,000 people – mostly labourers working outside in high temperatures in smaller urban settlements (Revi, 2008).	Flooding (also leading to disease), landslides (UN/POP/EGM-URB/2008/16) Heatwaves (Kovats and Aktar 2008). It is well documented that, in most cities, the urban poor live in the most hazardous urban environments – for instance on floodplains or other areas at high risk of flooding or unstable slopes (Hardoy, Mitlin and Satterthwaite, 2001). Worldwide, about one billion live in informal settlements, and this proportion is growing at about twice the rate of formal settlements.		A large proportion of those in informal settlements are especially susceptible to harm with limited ability to recover. Groups especially impacted include infants and older groups who are less able to cope with heat waves, and less able to escape floodwaters. Those who work outside without heat protection are also very vulnerable (UN/POP/EGM-URB/2008/16)	Climate change is likely to bring ever-increasing numbers of accidental deaths and serious injuries and increasingly serious damages to people's livelihoods, property, environmental quality and future prosperity – especially the urban poor in informal settlements (UN/POP/EGM-URB/2008/16). Poorer groups get hit hardest by this combination of greater exposure to hazards (e.g., a high proportion living on unsafe sites) with no or limited hazard-removing infrastructure, and high vulnerability due to makeshift housing with less capacity to cope due to a lack of assets, insurance, and marginal livelihoods, with less state support and limited legal protection. Low-income groups also have far less scope to move to less dangerous sites (UN/POP/EGM-URB/2008/16). Informal settlements are found in all regions, for example there are some 50 million people in such areas in Europe (UNECE 2009).	Ahern et al.(2005); Douglas et al.l (2008); Hardoy et al.(2001); Kovats and Akhtar (2008); Revi (2008); UNECE (2009)

Energy	Iberian Peninsula, Mediterranean regions	1920–2000	Hydroelectric productionrepresents, in an average year of precipitation, 20% of the total Spanish electricity production and 35% for Portuguese production. Other renewal energy sectors are being developed, mainly windpower and solar energy.	Low precipitation, Drought	Decrease in hydropower production	Economic sectors	Throughout most of the 20th century, North Atlantic oscillation (NAO) correlates with winter precipitation and river flow regimes for the three main international Iberian river basins, namely the Douro (north), the Tejo (centre) and the Guadiana (south). The impact of the NAO on winter river flow was quantified in terms of total Spanish potential hydroelectricity production. The important control exerted by the NAO and the recent positive trend in the NAO index contribute to a significant decrease in the available flow, and therefore, hydropower production in the Iberian Peninsula	Trigo et al., 2004

Tourism	Global	Current – short term	Most tourist enterprises are subject to weather conditions and are susceptible to harm from changes unless the changes are beneficial which may happen in some areas. Capacity to recover is likely to depend on teh degree of dependence on tourism with diversified economies being more robust. Low lying coastal areas and areas currently on the edge of the snow line may have limited alternatives. Some resorts will be able to adapt using snow machines, but some will fail (Elsasser & Bürki, 2002).	Heatwaves, cyclones, coastal erosion, disease outbreaks associated with changed climate. See impacts for detailed examples. Approximately 10% of global GDP is spent on recreation and tourism (Berrittella et al, 2005). The distribution of global tourism is expected to shift polewards due to increased temperatures associated with climate change. Parts of the Mediterranean, a very popular summer tourist spot, may become too hot in summer but more appealing in spring and autumn. More temperate tourist destinations are predicted to become more attractive in summer. Tourist seasons in different areas are expected to shift, with sem areas gaining whiel others lose (Amelung et al, 2007; Bigano et al, 2007).		Small island states are often dependent on tourism, and the tourism infrastructure that lies on the coast is threatened by climate change. The aviation industry is currently subject to very low or no taxes on greenhouse emissions. If an international carbon-pricing agreement were reached, this could have detrimental impacts on tourism globally, particularly following a period of historically low airfares (Amelung & Viner, 2006).	The main impact will be decline in revenue from tourism, with loss of livelihoods for those working in the sector.Tropics: Increase cyclone intensity, with wind speeds expected to increase up to 20% (Preston et al, 2006; World Bank, 2000). In the Caribbean, reduced tourist amenity as beaches erode with sea level rise, and degraded snorkelling and scuba activities due to coral bleaching (Uyarra et al, 2005).Alpine: heatwaves and rising temperatures raising the snow line. In Switzerland only 44% of ski resorts will be above the ‘snow-reliable’ altitude by approximately 2030, as opposed to 85% today (Elsasser & Bürki, 2002).Disease: Ross River fever outbreaks in Cairns, Australia, have a significant impact on the local tourist industry. The conditions for an outbreak such as increased temperatures and humidity are predicted to increase under climate change (Tong & Hu, 2001). Calgaro & Lloyd (2008) argue that political and economic incentives exist to suppress information about the coastal hazards in an effort to attract tourism, and that this cost both lives and livelihoods in Khao Lak.The aviation industry is currently subject to very low or no taxes on greenhouse emissions. If an international carbon-pricing agreement were reached, this could have detrimental impacts on tourism globally, particularly following a period of historically low airfares (Amelung & Viner, 2006).	Amelung et al (2007); Amelung & Viner (2006) ; Berrittella et al (2006); Bigano et al (2007); Calgaro & Lloyd (2008); Elsasser & Bürki (2002); Preston, B et al (2006); ; Tong & Hu (2001); Uyarra et al (2005); World Bank (2000)
Tourism	Mediterranean countries	Present	High in coastal areas and snow-related tourism	High summer temperatures, Heat waves (tropical nights), droughts	Decrease in number of tourist, change of tourism season	Tourist local services, travel-related industry	Change on the tourist behaviour, decreasing the stay period, delaying the travel decision, changing the selection of destination. Increase on travelling and holidays during transition seasons (spring and autumn)	Perry (2003); Esteban Talaya et al. (2005)

Tourism	world, regional	Near term	-	climtatic variation	tourism demand		Variations in tourist flows will affect regional economies in a way that is directly related to the sign and magnitude of flow variations. At a global scale, climate change will ultimately lead to a welfare loss, unevenly spread across regions.	Berrittella et al.(2006)
Tourism	EU countries	Near past	-	climate	tourist destination		For European countries during the summer months, there would be an increase in attractiveness; however, the northern European countries become relatively more attractive closing the gap on the currently popular southern European countries.	Hamilton (2003)
Economy (insurance)	US, Japan, Europe	Long-term (2080s)	No change (Assuming the status quo for future)	Change in windstorm characteristics. All exposure information (location and density of population and property, physical characteristics of the property, asset values) was kept constant at today's values.	Annual average insured loss Insured loss with chance of occurring once every 100 years Insured loss with chance of occurring once every 250 years	-	This study focuses on one of the most costly aspects of today's weather – hurricanes, typhoons, and windstorms, because of their potential to cause substantial damage to property and infrastructure. Annual losses from the three major storm types affecting insurance markets (US hurricanes, Japanese typhoons and European windstorms) could increase by two-thirds to $27 bn by the 2080s. Focussing on the most extreme storms (losses occurring once every 100 to 250 years), by the 2080s climate change could: • Increase wind-related insured losses from extreme US hurricanes by around three-quarters to total $100 – 150 bn. • Increase wind-related insured losses from extreme Japanese typhoons by around two thirds to total $25 – 34 bn (¥2,700 – 3,700 bn). • Increase wind-related insured losses from extreme European storms by at least 5% to $32 – 38 bn (€25 – 30 bn).	ABI (2005)
Economy	Indonesia	Current	-	flooding	Food shortage, water and soon	Economic sectors,health, community,et al	Climate change threatens to undermine Indonesia's efforts to combat poverty.Livelihoods – The effects of climate change are being felt more acutely by the poorest communities.Health –Heavy rainfall and flooding can overwhelm rudimentary systems of sanitation in slum areas of towns and cities,exposing people to water-borne diseases such as diarrhoea and cholera.Food security – The poorest regions are also likely to suffer food shortages.Water – Changing rainfall patterns are also reducing the availability of water for irrigation and for drinking.	UNDP (2007)
Climate system	Tropical forests	1960-current	-	Extreme deforestation	Change in precipitations patterns		A drastic deforestation scenario would result in a severe restructuring of land–atmosphere dynamics, partially explaining why most AGCMs have predicted weakened water fluxes as a result of extensive deforestation. A basin-wide deforestation scenario would impose a severe decline on evapotranspiration and then on precipitation recycling, weakening the hydrological cycle in Amazonia as a whole.	D'almeida et al.(2007)

Others	Viet Nam	2009	-	disasters, food shortage,health, et al	employment, health ,livelihood,working of women	gender equality	The poor,women and children are among the most vulnerable to climate change effects, and climate change may in fact worsen gender inequalities, create extra work for women,and exacerbate vulnerability of women in poor households. Yet gender has to date been relatively neglected in research and policy analysis, as well as in international and national policy processes.	Oxfam and UNDP (2009)

Table 4-12: Impact of climate change by 2071-2100 on flood risk in Europe (Ciscar, 2008). Note that the numbers assume no change in population or development in flood-prone areas

Region	B2: HadAM3h (2.5°C)	A2: HadAM3h (3.9°C)	B2: ECHAM4 (4.1°C)	A2: ECHAM4 (5,4°C)	1961-1990
Additional expected population affected (1000s/year)					Baseline
Northern Europe	-2	9	-4	-3	7
British Isles	12	48	43	79	13
Central Europe (north)	103	110	119	198	73
Central Europe (south)	117	101	84	125	65
Southern Europe	46	49	9	-4	36
EU	276	318	251	396	194
Additional expected economic damage (million €/year, 2006 prices)					Baseline
Northern Europe	-325	20	-100	-95	578
British Isles	755	2854	2778	4966	806
Central Europe (north)	1497	2201	3006	5327	1555
Central Europe (south)	3495	4272	2876	4928	2238
Southern Europe	2306	2122	291	-95	1224
EU	7728	11469	8852	15032	6402

Table 4-13: Identification of extreme impacts affecting the tourism sector by regions. Sources: IPCC 2007; Ehmer and Heymann, 2008; Scott et al., 2008]

Regions/ subregions	Tourism value exposed to hazard	Sub-sectors vulnerability	Potential extreme impacts
Mediterranean countries	- Tourism highly dependent on climate - Contribution of GDP: Spain (17%), Portugal (14%), France (9%), Italy (9%), Greece (16%); Turkey (11%), Croatia (17%), Morocco (16%), Tunisia (17%)	- Summer exceeding comfortable temperature levels highly vulnerable in Spain, Portugal, Greece, Turkey and islands (Malta, Cyprus) -Cultural and city holidays unaffected -Ski resorts outside glaciers highly vulnerable. Lack of flexibility of snow touristic destinations	- Heat waves, days exceeding 40ºC and tropical nights - Droughts, and water shortage - Lack of snow, water demand for artificial snow production - Increase risk of forest fires - Return of diseases (e.g. malaria) cannot be ruled out - More frequent flooding affecting new urbanized areas - More intense coastal storms (beach erosion)
Central Europe	- Tourism slightly dependent on climate - Contribution of GDP: Germany (8%), Benelux countries (8%), UK (4%), Ireland (4%), Austria (15%), Switzerland (13%)	- Positive effects for activity holidays on northern coastal areas - City tourism (15%) unaffected - Heath resorts non affected - Ski tourism with a shorter season in Alps. - Higher-lying winter sports resorts may escape adverse snow conditions.	- Longer summer season - Heat waves to increase in countries no adapted to high temperatures. - Summer floods in central European rivers and southern UK - Lack of snow in the low elevation ski resorts during winter: - High risk of coastal erosion to affect Britain coastal resorts. - Rising sea level and the risk of flooding in low lands of The Netherlands.
Northern Europe	- Tourism seasonal non dependent on climate - Contribution of GDP: Denmark (8%), Sweden (6%), Norway (7%),	- Positive effects for seaside summer holidays, particularly in Denmark and Sweden - Tourism emphasis on nature to increase due to longer season - Reliable snow cover will be maintained (at	- Extended summer season - Winter snow conditions may be deteriorated at low altitudes but improved during winter due to increased snow precipitation amount.

	Findland (8%), (15%), (13%)	least until 2050s)	
Eastern Europe	- Tourism non dependent on climate - Contribution of GDP: Estonia (14%), Slovakia (13%), Czech Republic (12%), Bulgaria (12%), Slovenia (12%), Ukraine (8%), Hungary (7%), Poland (7%), Lithuania (7%), Russia (6%), Romania (5%), Latvia (4%)	- Cultural tourism less sensitive to climate change - Countries bordering Black Sea may benefit from climate impacts in nearby regions - Decrease lake levels may interfere with water sports - Summer convalescence and health tourism is no vulnerable to climate impacts. - Winter sport tourism to face problems by 2030s	- Droughts and higher evaporation to affect lake resorts and mountain landscapes - Decreasing duration of snow season
Caribbean	- Tourism highly dependent on climate. Contribution of GDP: Puerto Rico (6%), Cuba (7%), Dominican Republic (14%), Jamaica (33%), Bahamas (51%)	- None effect of temperature rise - Major impacts from weather extremes in high vulnerable economies - Increasing incidence of vector-borne diseases	- Tropical storms to increase - Water shortage - Coastal erosion by storms - Coral bleaching - Loss of biodiversity
North America	- Tourism slightly dependent on climate - Contribution of GDP: USA (9%), Canada (10%),	- Positive effects on nature and adventure tourism. - Skii in Rocky Mountains less severely affected than Alps.	- Extended summer season - Increase in hurricane intensity in SE USA. - Droughts and forest fires in SW USA
Latin America	- Tourism slightly dependent on climate - Contribution of GDP: Mexico (13%),	- Tours to landscape and cultural factors (Maya ruins, Machu Picchu) slight climate dependence - Rising temperatures and natural disaster to	- Rising temperatures and heat waves. - Droughts and water shortage - More intense tropical storms to cause damage of infrastructures

	Argentina (6%), Brazil (5%)	affect negatively in tourist comfort at seaside resorts. - Increasing incidence of vector-borne diseases	
Asia	- Tourism highly dependent on climate - Contribution of GDP Indonesia (6%), Thailand (13%), Philippines (6%), Sri Lanka (8%), Malaysia (12%), India (4%)	- Cultural and landscape tourism popular in Asia is less climate-sensitive - Sea side resorts negatively affected by rising temperatures - Increasing incidence of vector-borne diseases - Philippines highly vulnerable to increase weather extremes - Tourism sector to remain a growing sector despite of climate change	- Coral bleaching to reduce attractiveness of diving regions (eg. Bali) - Increasing problems of water supply - Floods during monsoon season can be worsen. - Landslides in steep mountain areas - Higher severity of cyclones to produce high damage and socio-economic disruption - Coastal erosion to increase (e.g. India and Asian delta areas)
Island states	- Tourism highly dependent on climate - Contribution of GDP Maldives (58%), Seychelles (55%), Mauritius (24%)	- Loss of biodiversity and coral bleaching may affect diving tourism. - Sea level rise to affect low-lying Maldives archipelago	- Possible reduction of precipitation with subsequent water supply problems - Coral bleaching
Africa	- Tourism highly dependent on climate - Contribution of GDP Tanzania (%), Kenya, South Africa	- Loss of biodiversity and desertification. Infrastructure protected by naturally vegetated coastal dunes, were better protected than those with sea walls (e.g. Natal coast of South Africa). - Loss of natural resources for wildlife - South Africa is the less climate-	- Droughts and increase aridity - Flooding and heavy rainfall to increase - Water shortage - Extreme wind events (cyclones) and storm surges leading to structural damage and shoreline erosion in Mozambique.

		dependent country - Increasing incidence of vector-borne diseases	
Australia/ Oceania	- Tourism slightly dependent on climate - Contribution of GDP Australia (11%), New Zealand (11%), Pacific Islands	- City tourism non-sensitive to climate impacts - Australian outback tourism to seasonal readjusts to avoid high temperatures - Australia: Tourism activity to be centered during austral winter - Adventure holidays and green holidays to benefit in New Zealand	- Coral bleaching to affect attrativeness of the Great Barrier Reef - Queensland region subject to flooding - Droughts and water shortages to increase in Australia - Forest fires to increase in New South Wales - Sea level rise derived problems to affect South Seas archipelagos and Polynesia
Middle East	- Tourism highly dependent on climate - Contribution of GDP Egypt(%), United Arab Emirates (%)	- Loss of comfort resulting from rising temperatures in summer months - Winter tourism to increase. Seaside tourists to avoid summer months. - Cultural tourism less susceptible to climate impacts	- High temperatures and heat waves - Water shortage - Coral bleaching to affect Read Sea reefs

Table 4-14: Summary of climate extremes in Europe – hazard, exposure, vulnerability, and impacts.

Climate extreme	Changes in hazard	Exposure	Vulnerability	Impacts
Heat wave	Increase in frequency and severity (observed and projected)	Ageing society. Prevailing urban population	Old, sick, and lonely suffer most. Conditions for summer tourism industry in the south deteriorate	Tens of thousands of additional deaths during the heat wave in summer of 2003. Heat-related deaths likely to increase
Cold wave	Decrease in frequency and severity (observed and projected)	Throughout most of Europe	Homeless, people under influence of alcohol	Despite the warming, during some of winters in 2000s, cold waves kill hundreds. Adverse effects of warmer winters in agriculture (pest thrive)
Intense precipitation, river flood, landslide	Increase in mean precipitation intensity observed and projected. No ubiquitous increase of annual maximum river flow observed. Large changes in flood risk are projected (see Fig. X), but uncertainty in projections is considerable	Population of flood-prone and slide-prone areas	Uninsured / uninsurable households	Summer 2002 flood resulted in material damage of 20 billion Euro. Over much of the continent, a 100-year flood in the control period will be more frequent in the future.
Drought	No robust change of drought properties observed. Projections of increasing frequency and severity of summer droughts over much of Europe	Throughout the continent	Particularly adverse effects in the south	Drought of summer 2003 resulted in multi-billion material damage
Wild fire	Often accompanying heat wave and drought (on the rise). Increase in Fire Weather Index is projected.	Throughout the continent	Semi-arid areas of Southern Europe. Pine forests (largely monocultures) in Central Europe	Large, and destructive, wild fires in 1992 (Central Europe), 2003 (Southern Europe), and 2007 (Greece). In the Mediterranean over 0.5 million ha has burnt annually

Gale wind	Some increase in extreme wind speeds in parts of Europe (observations and projections), but low confidence in projections	Infrastructure, forests. Increase of total growing stock in forest	Light-weight roofs, pylons of transmission lines. Age class and tree species distribution in forests. Conifers are more vulnerable to wind damage than broadleaved species	Very high material and environmental damage, e.g. of the order or 10 billion Euro in December 1999 (storms: Anatol, Lothar, Martin). On 8 Jan 2005, the Erwin (Gudrun) storm over 75 million m^3 of windfall timber damage in Southern Sweden
Coastal flooding	Increase in storm surges accompanying sea-level rise	Increasing number of population inhabiting European coasts	Cliff coasts, low-lying coasts	Projections show increasing number of people suffering from coastal flooding (Fig. X)
Snow deficit	More frequent and more severe (observed and projected)	Winter tourism industry	Lower-elevation stations	Considerable reduction of the number of skiing days

Table 4-15: Climate extremes, vulnerability and impacts

Climate Extreme	Changes in Climate Extremes	Exposure	**Vulnerability**	**Impacts**
Tropical Cyclones	Possibly lower frequency but increasing magnitude	Very high for atolls and coastal communities. High for most countries. Low for PNG Highlands, Nauru and Kiribati (too close to equator).	Reduction of traditional coping measures.	Greater levels of mortality, injury and hardship. Housing agriculture and infrastructure damage
• Wind	Increased wind speeds (?)	Houses, some food crops, tree crops, electricity and communications lines	Expansion of coconut as a commercial crop and tapioca as an alternative to traditional staples such as taro and yams. Transitional housing and squatter settlements.	Destruction of homes, loss of food security, disruption of commercial livelihoods. Destruction/damage to infrastructure
• Rain	Increased rainfall intensities	See intense rainfall events	See intense rainfall events	
• Storm Surge	Increased storm surge heights, exacerbated by sea level rise and coral reef degradation	Coastal areas of all islands and atolls. Ghyben-Herzberg lens of atolls exposed to salinisation	Urban growth (most towns are coastal). Tourism development.	Damage to coastal communities (housing, infrastructure, crops), Salinisation of Gyben-Herzberg lens on atolls
Intense Rainfall Events	Increased rainfall intensities			
• River Flooding	Increased flood events	Large inter-plate islands with well developed river systems and flood plains as well as deltas, both heavily populated. Flash floods on volcanic high islands with small catchments.	Watershed deforestation, increasing population densities	Destruction/damage to settlements and crops, to infrastructure (roads and bridges).
• Land/mud slides	Increased land/mud slide events	Locations at the base of slopes	Increased through deforestation	Destruction/damage to settlements and crops, to infrastructure (roads and bridges).
Drought	Increased frequency and magnitude (duration, severity of rainfall decrease) of drought events	Throughout region, especially atolls, PNG Highlands	Increasing density urban population densities, especially in atoll countries	Reduced water quantity and quality, health problems, reduce agricultural productivity

Frost (PNG Highlands)	Reduction in occurrence? But droughts may increase in magnitude and frequency	Papua New Guinea Highlands	Traditional responses reduced by relief programmes	?
King tides and high wave events	Exacerbated by sea level rise	Low lying coastal areas and atolls	Urban growth (most towns are coastal). Tourism development.	Salinisation of Ghyben-Herzberg lens on atolls, coastal flooding.
Tsunami	Non climate but exacerbated by sea level rise and coral reef degradation	Low lying coastal areas and atolls	Urban growth (most towns are coastal). Tourism development.	Destruction of buildings, infrastructure and crops at elevations higher than would otherwise be the case.

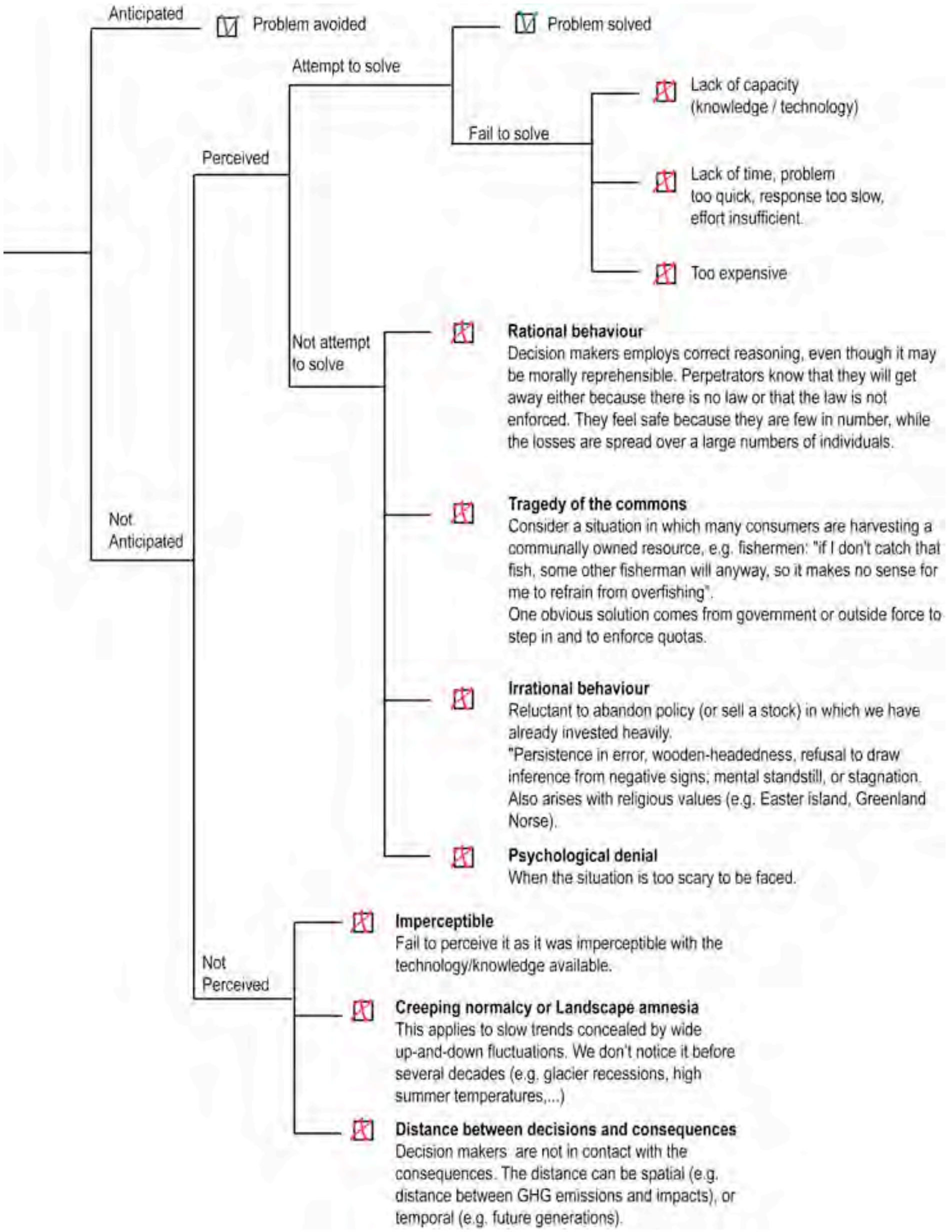
Table 4-16: Pacific Island type and exposure to risks arising from climate change

Island Type	Exposure to climate risks
Plate-Boundary Islands Large High elevations High biodiversity Well developed soils River flood plains Orographic rainfall	Located in the western Pacific these islands are exposed to droughts. River flooding is more likely to be a problem than in other island types. Exposed to cyclones, which cause damage to coastal areas and catchments. In PNG high elevations expose areas to frost (extreme during El Nino), however highlands in PNG are free from tropical cyclones. Coral reefs are exposed to bleaching events. Most major settlements are on the coast and exposed to storm damage and sea-level rise.
Intra-Plate (Oceanic) Islands **Volcanic High Islands** Steep slopes Different stages of erosion Barrier reefs Relatively small land area Less well developed river systems Orographic rainfall	Because of size few areas are not exposed to tropical cyclones, which cause most damage in coastal areas and catchments. Streams and rivers are subject to flash flooding. Most islands are exposed to drought. Barrier reefs may ameliorate storm surge and tsunami. Coastal areas are the most densely populated and exposed to storm damage and sea level rise. Localised freshwater scarcity is possible in dry spells. Coral reefs are exposed to bleaching events.
Atolls Very small land areas Very low elevations No or minimal soil Small islets surround a lagoon Shore platform on windward side Larger islets on windward side No surface (fresh) water Ghyben Herzberg (freshwater) lens Convectional rainfall	Exposed to storm surge, 'king' tides and high waves, although exposure to cyclones is much less frequent than in islands to the west and south. Flooding arises from high sea-level episodes. Exposed to fresh water shortages and drought. Fresh water limitations may lead to health problems. Coral reefs are exposed to bleaching events. All settlements are highly exposed to sea-level rise.
Raised Limestone Islands Steep outer slopes Concave inner basin Sharp karst topography Narrow coastal plains No surface water No or minimal soil	Depending on height may be exposed to storm surges and wave damage during cyclones and storms. Exposed to fresh water shortages and drought. Fresh water problems may lead to health problems. Flooding is extremely rare. Coral reefs are exposed to bleaching events. Settlements are not exposed to sea-level rise.

Source: Campbell (2006)

Table 4-17: Climate related disaster occurrence and regional average impacts from 2000-2008
Sources: Vos F, Rodriguez J, Below R, Guha-Sapir D. *Annual Disaster Statistical Review 2009: The Numbers and Trends*. Brussels: CRED; 2010. page 5-7, page25.

Sub group of disasters (type)		Africa	Americas	Asia	Europe	Oceania	Global
Climatological (storm)	No. of Disasters	*9*	*13*	*13*	*17*	*1*	*54*
	Damages (2009 US$ bn)	*0.05*	*2.36*	*3.47*	*3.15*	*0.36*	*9.39*
Meteorological (Extreme Temperature, Drought, Wildfire)	No. of Disasters	*9*	*35*	*42*	*15*	*7*	*108*
	Damages (2009 US$ bn)	*0.08*	*39.93*	*10.30*	*3.01*	*0.31*	*53.63*
Hydrological (flood, land slides, etc)	No. of Disasters	*42*	*39*	*81*	*26*	*5*	*194*
	Damages (2009 US$ bn)	*0.37*	*2.99*	*9.05*	*7.01*	*0.52*	*19.94*
Total average	No. of Disasters	*60*	*87*	*136*	*58*	*13*	*356*
	Damages (2009 US$ bn)	*0.50*	*45.28*	*22.82*	*13.17*	*1.19*	*82.96*



Rational behaviour
Decision makers employs correct reasoning, even though it may be morally reprehensible. Perpetrators 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 numbers of individuals.

Tragedy of the commons
Consider a situation in which many consumers are harvesting a communally owned resource, e.g. fishermen: "if I don't catch that fish, some other fisherman will anyway, so it makes no sense for me to refrain from overfishing".
One obvious solution comes from government or outside force to step in and to enforce quotas.

Irrational behaviour
Reluctant to abandon policy (or sell a stock) in which we have already invested heavily.
"Persistence in error, wooden-headedness, refusal to draw inference from negative signs; mental standstill, or stagnation.
Also arises with religious values (e.g. Easter island, Greenland Norse).

Psychological denial
When the situation is too scary to be faced.

Imperceptible
Fail to perceive it as it was imperceptible with the technology/knowledge available.

Creeping normalcy or Landscape amnesia
This applies to slow trends concealed by wide up-and-down fluctuations. We don't notice it before several decades (e.g. glacier recessions, high summer temperatures,...)

Distance between decisions and consequences
Decision makers are not in contact with the consequences. The distance can be spatial (e.g. distance between GHG emissions and impacts), or temporal (e.g. future generations).

Figure 4-1: A path model to societal success or failure
Schema based on Diamond (2005), pp. 419-440.

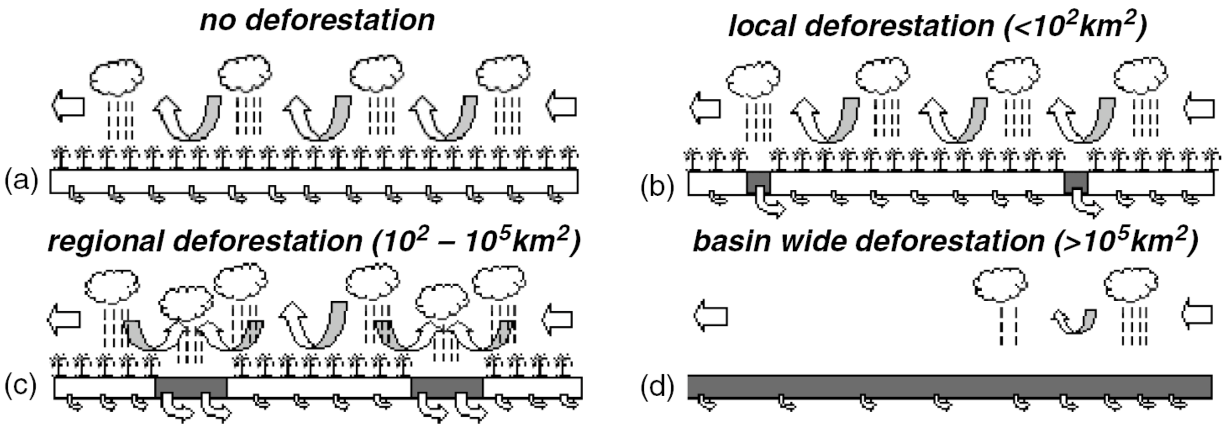


Figure 4-2: Tropical forest fires. Schematic representation of the hydrological impact of different extents of clearing (in dark gray) in Amazonia. The horizontal water vapor flux transfers moisture into the region and in the case of (a) no deforestation, this flux is sustained by precipitation recycling, maintaining high indices of rainfall. Areas of (b) local deforestation are too small to affect rainfall, but runoff increases and evapotranspitation decreases. Areas of (c) regional deforestation are large enough to influence circulation, strengthening convection and potentially increasing rainfall. A (d) basin-wide deforestation scenario would impose a severe decline on evapotranspiration and then on precipitation recycling, weakening the hydrological cycle in Amazonia as a whole. Sources: (D'Almeida et al., 2007)

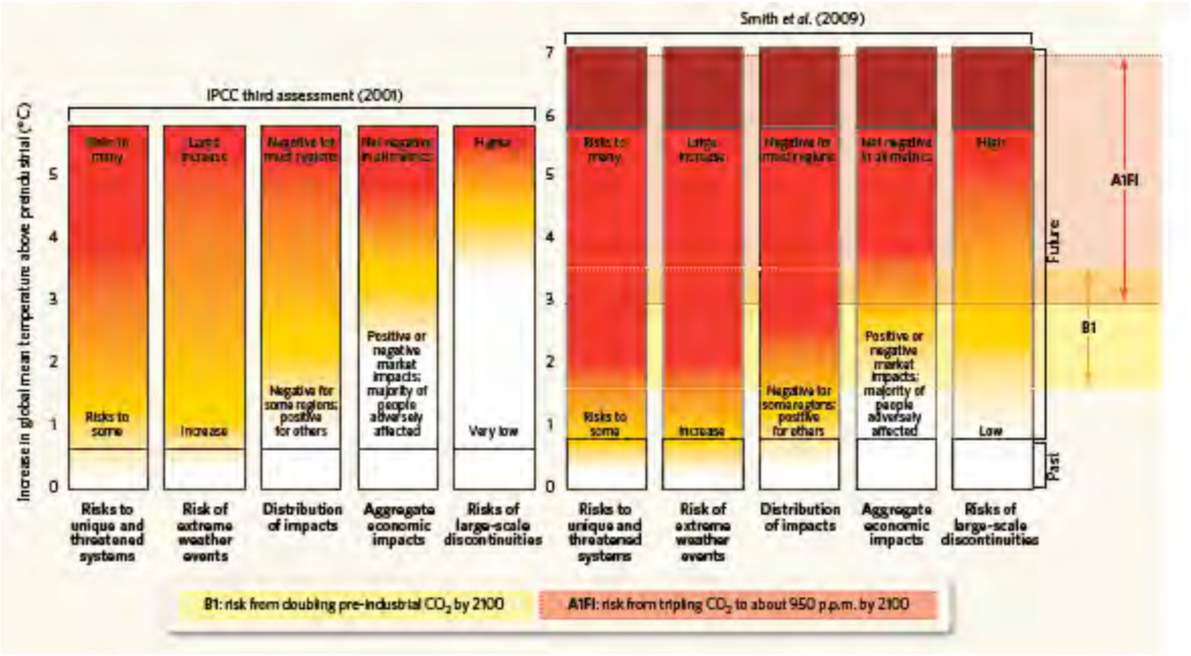


Figure 4-3: Burning embers. Source: Schneider, 2009

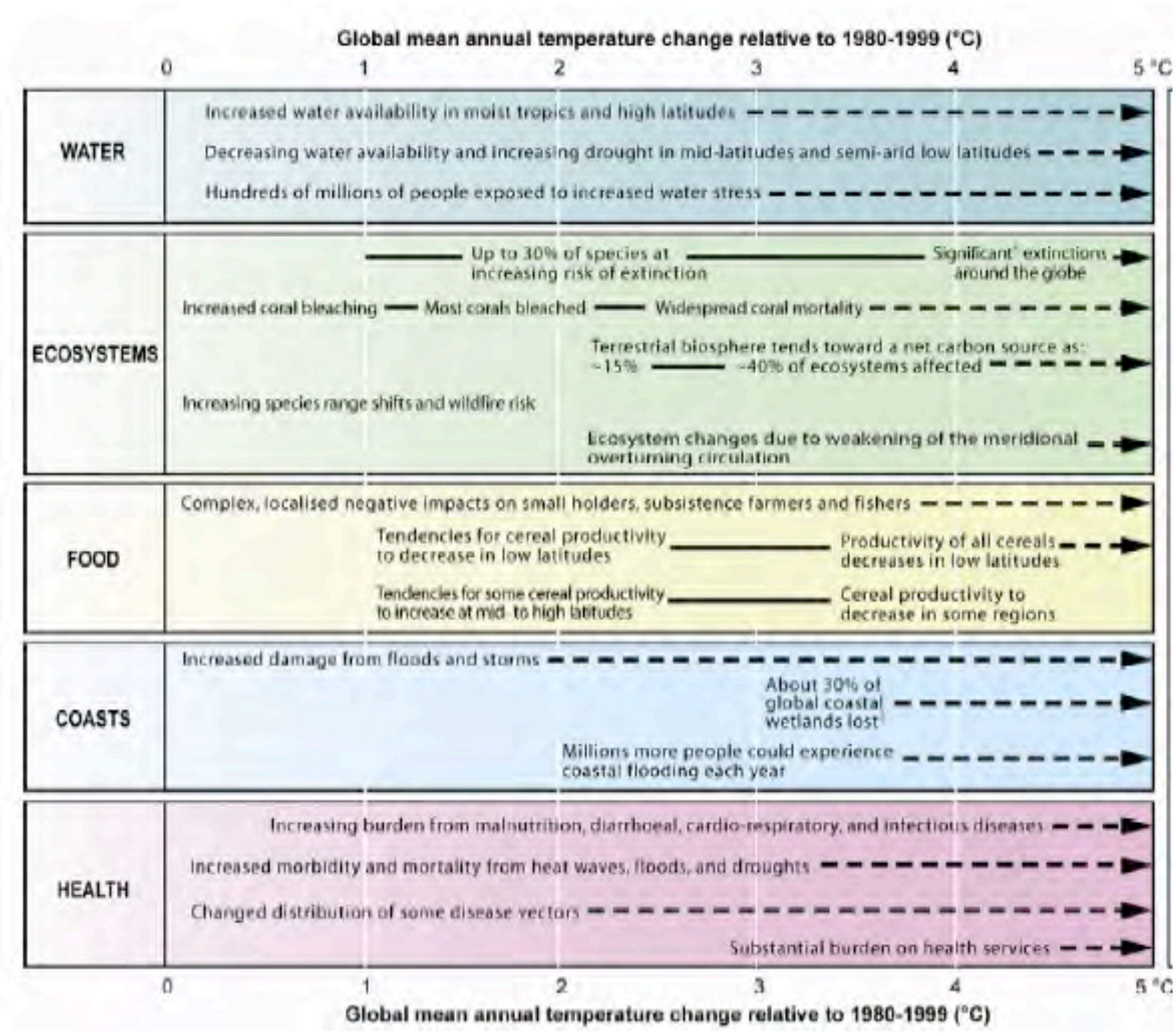


Figure 4-4: Global impacts of climate change.

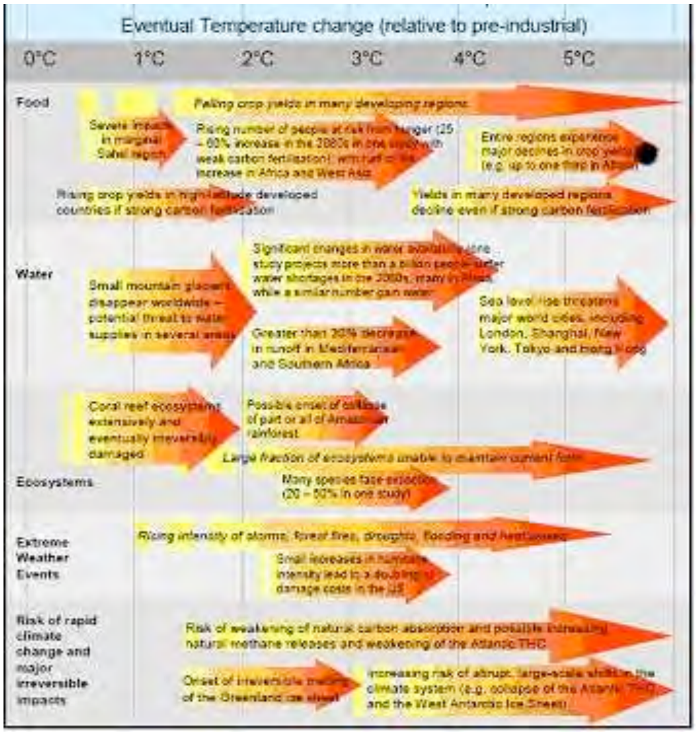


Figure 4-5: Illustrative examples of global impacts projected for climate changes.
Source: Stern (2006).

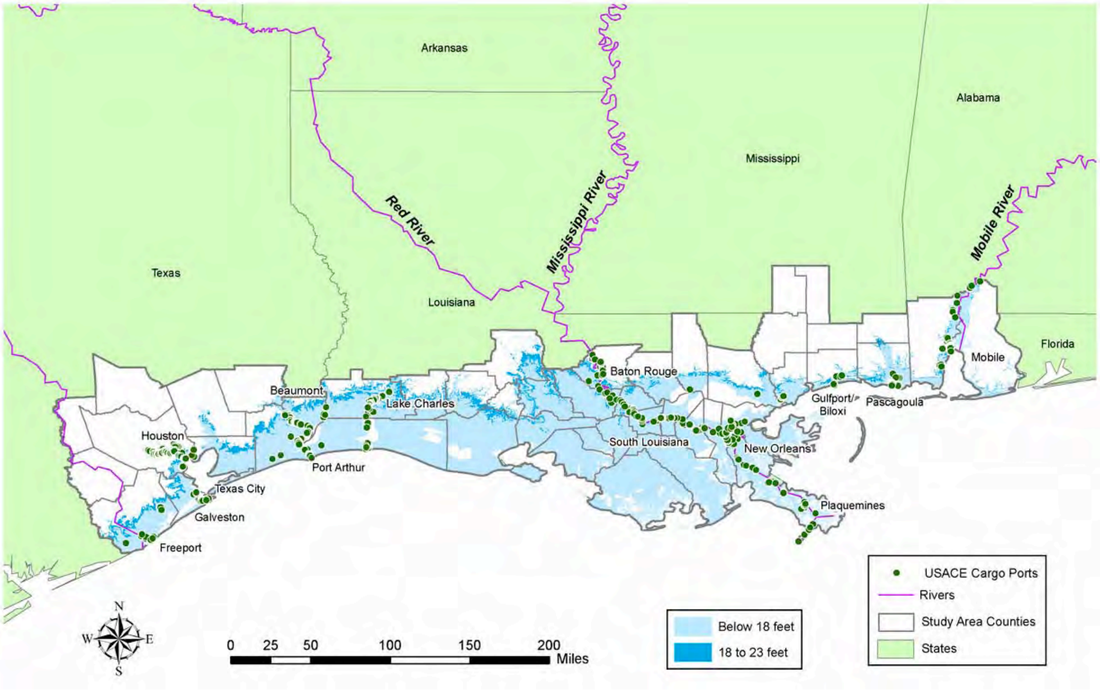


Figure 4-6: Freight handling port facilities at risk from storm surge of 5.5 and 7.0 m in the US Gulf coast (From CCSP, 2008, Fig. 4.20).

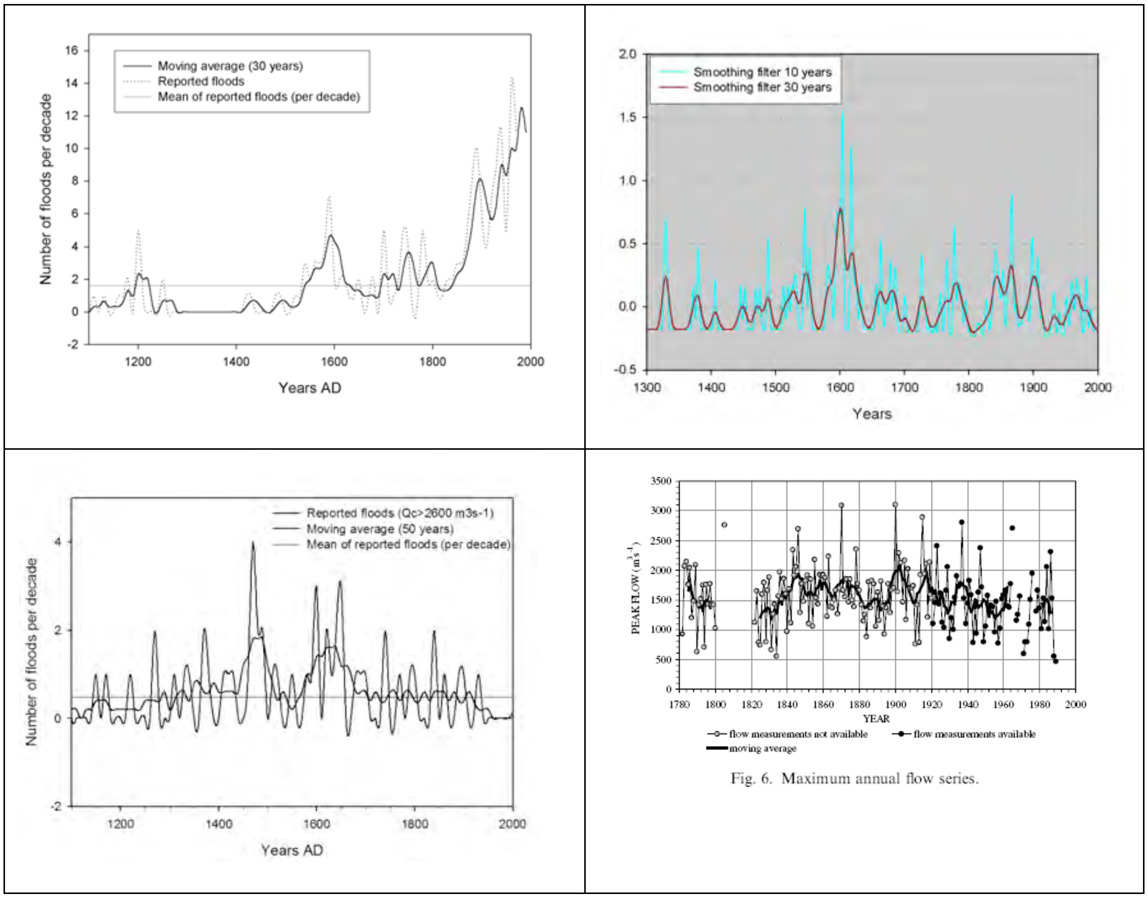


Figure 4-7: Temporal distribution of frequency of large floods Upper left: Temporal distribution of frequency of large floods per decade for the Tagus River (upper left; Benito et al., 2003), Spanish Mediterranean Rivers (upper right; after Barriendos, 2002), Tiber River (lower left; Camuffo et al., 2003). Lower Right: Maximum annual flood series for the Tiber River (after Calenda et al., 2005). The Tiber had two major periods of increased overflowing the Tagus River frequency.

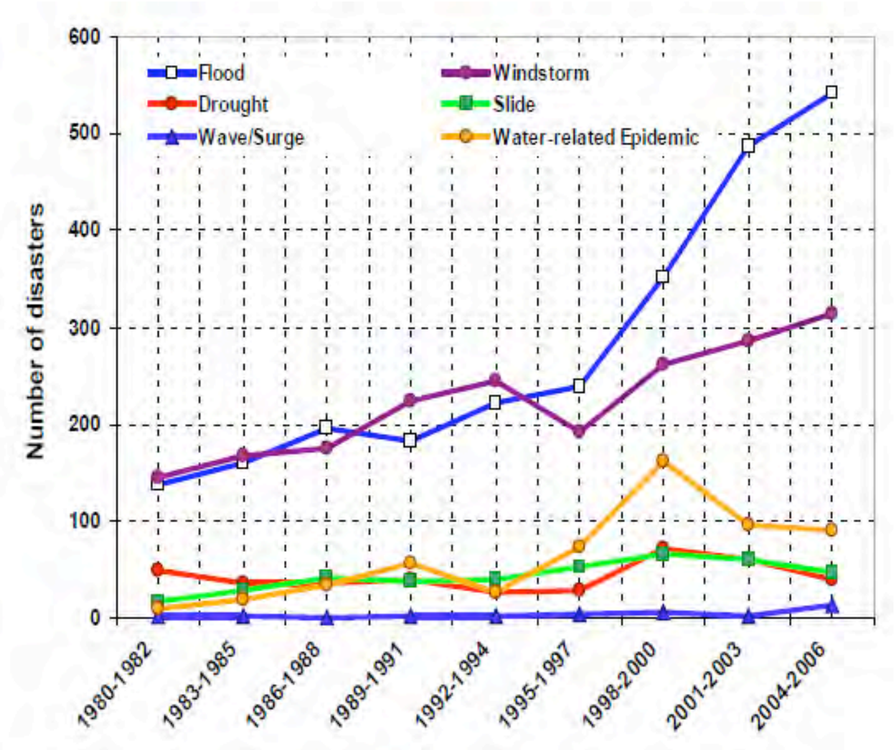


Figure 4-8: Water-related disaster events recorded globally, 1980 to 2006 (Adikari and Yoshitani, 2009)

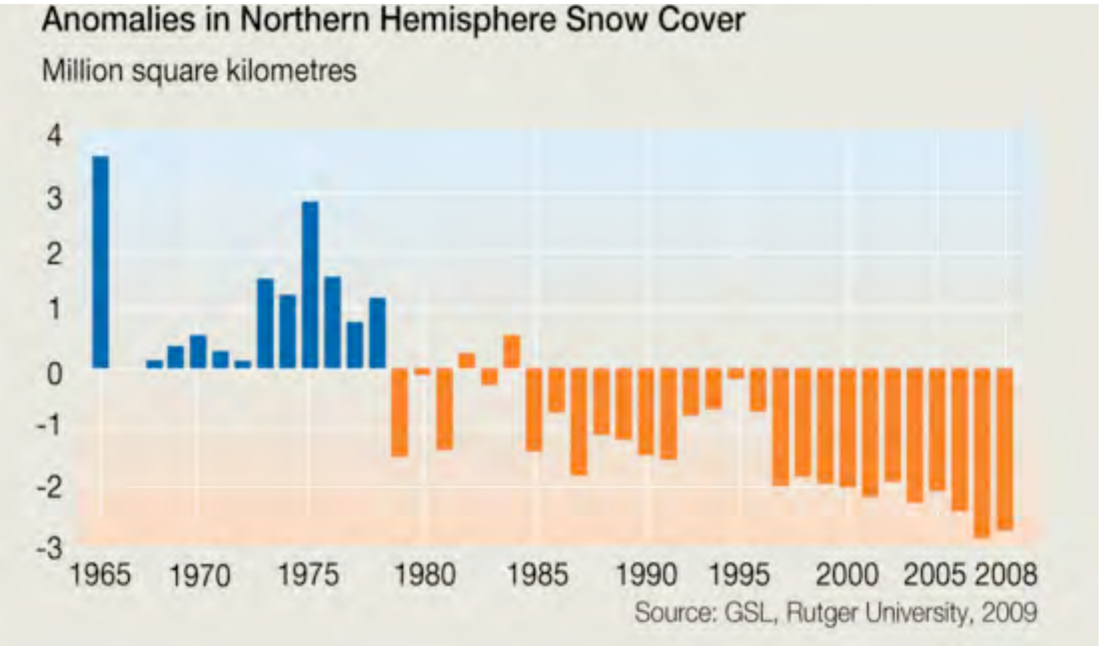


Figure 4-9: Anomalies in northern hemisphere snow cover since 1965 (UNEP, GRID).

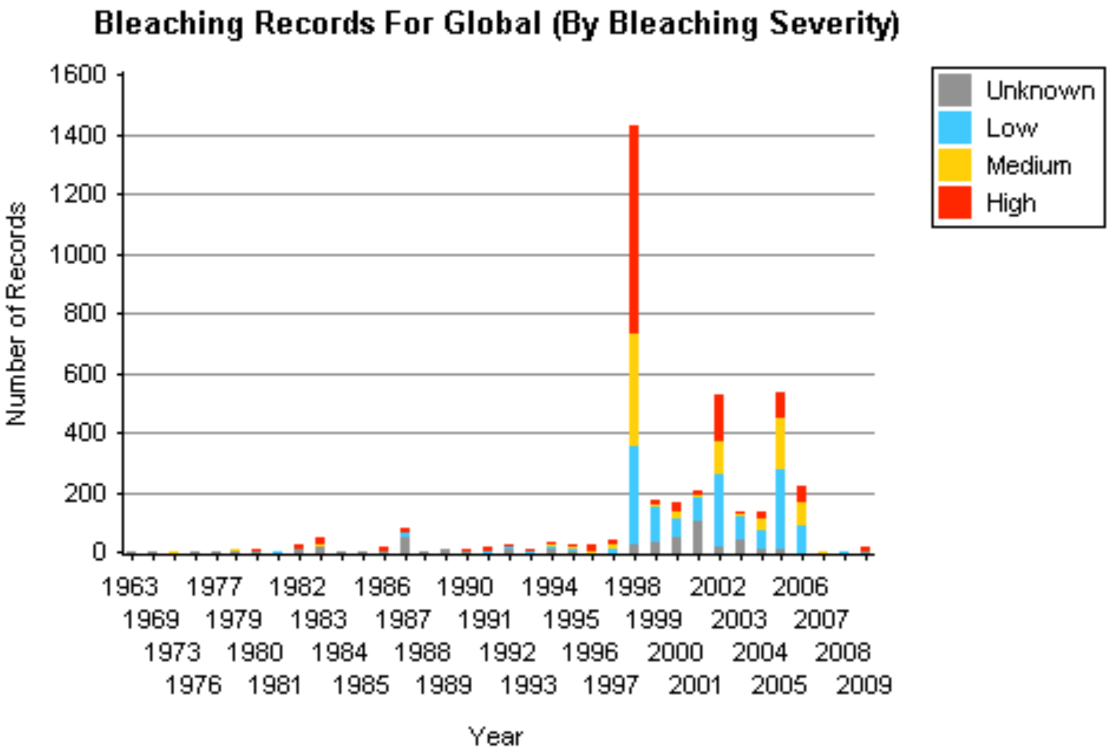


Figure 4-10: Coral bleaching records.

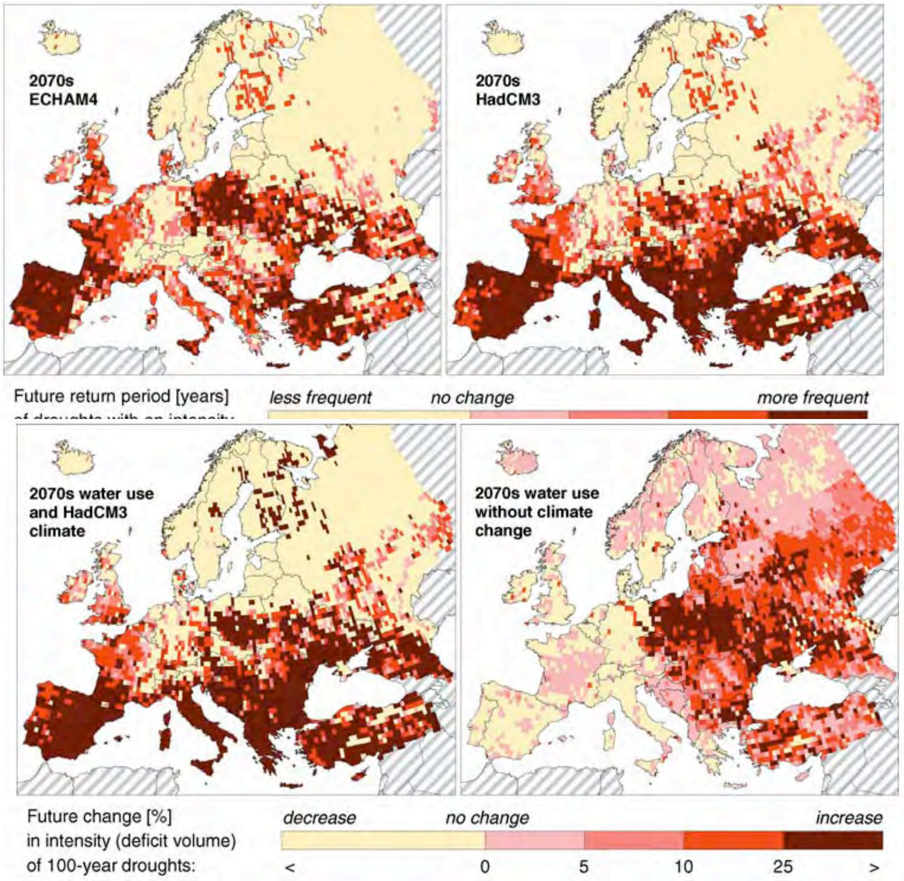


Fig 4-11: Change in indicators of water resources drought across Europe by the 2070s (Lehner et al., 2006). a (top): change in the return period of the current 100-year drought deficit volume, with change in river flows and withdrawals, under two climate scenarios. b (bottom): change in the intensity (deficit volume) of the 100-year drought with changing withdrawals, with climate change (left, with the HadCM3 scenario) and without climate change (right)

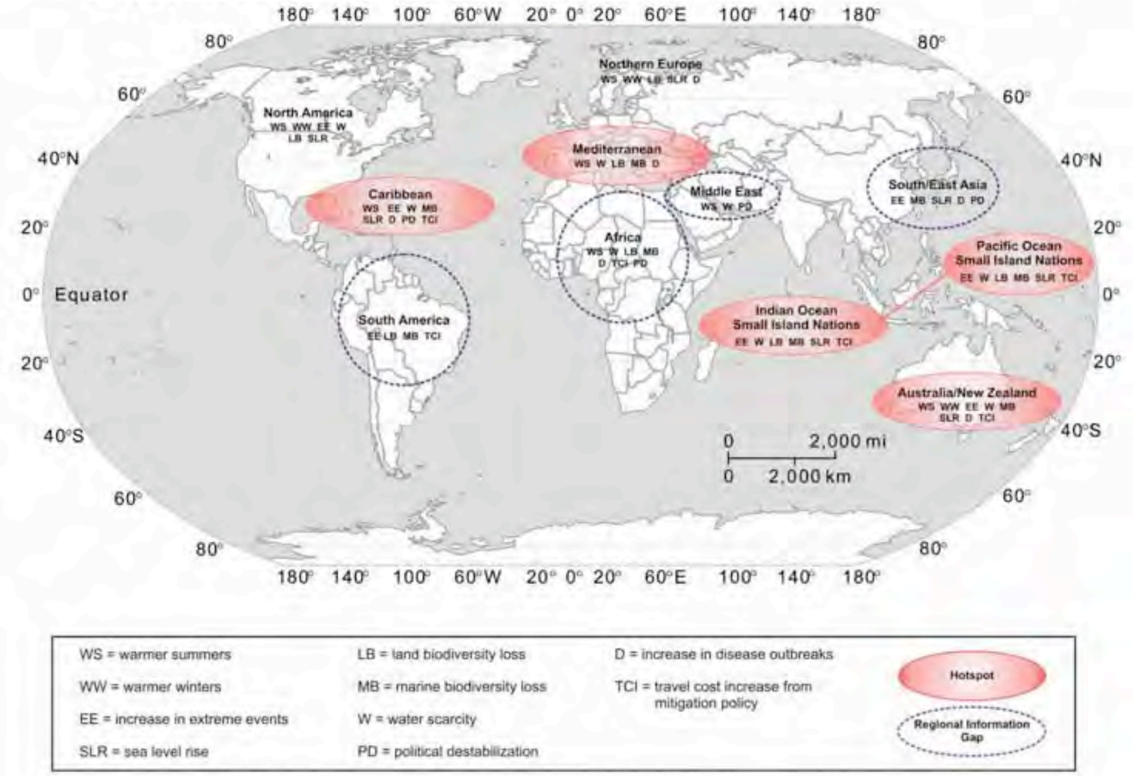


Fig 4-12: Climate change vulnerability hotspots in the tourism sector (Scott et al., 2008)

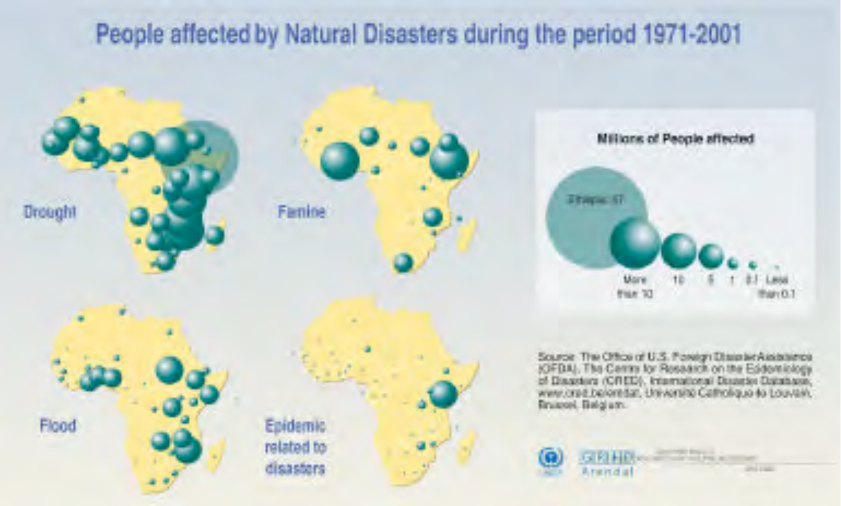


Figure 4-13: People affected by natural disasters from 1971-2001

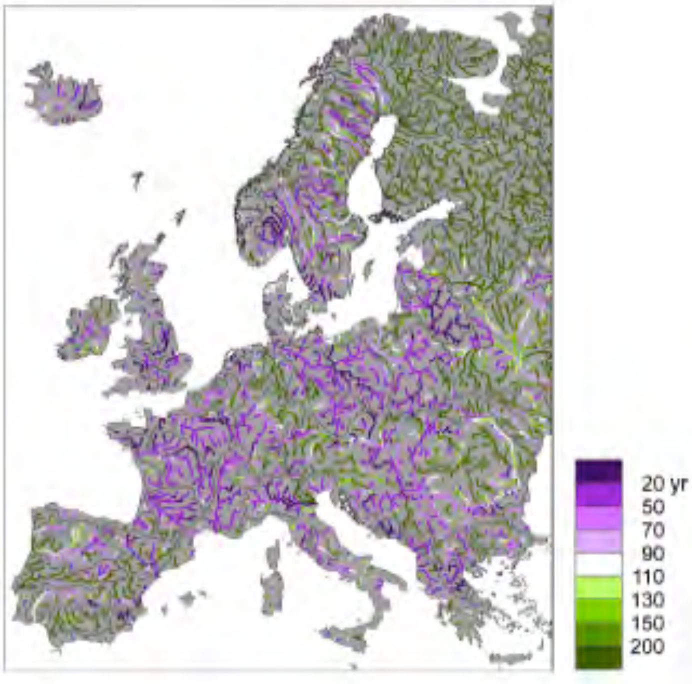


Figure 4-14: Recurrence interval of today's 100-year floods.

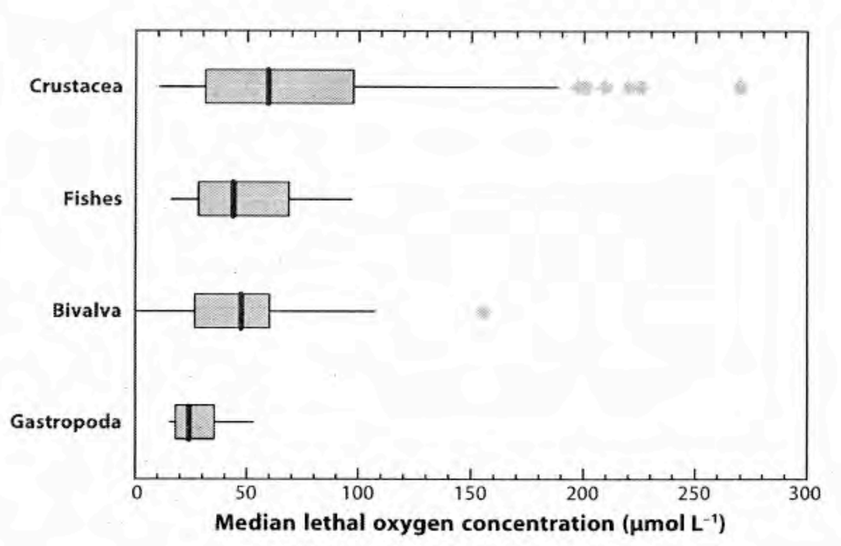


Figure 4-15: Median lethal oxygen concentration (μmol L^{-1}. Median lethal oxygen concentration (*LC*$_{50}$, in μmol L^{-1}) amoung four different taxa. The box runs from the lower (Q_1, 25%) to the upper (Q_3, 75%) quartile and also includes the median (*thick vertial line*). The range of data points not considered outliers is defined as 1.5 times the difference betweeen the quartiles (Q_3-Q_1), also known as interquartile range (IQR). The whiskers show the location of the lowest adn highest datum within this range, i.e., 1.5 * IQR. Shaded diamonds are outliers as per this definition. Redrawn after Vaquer-Sunyer & Duarte (2008). Copyright (2008) National Academy of Sciences, U.S.A.

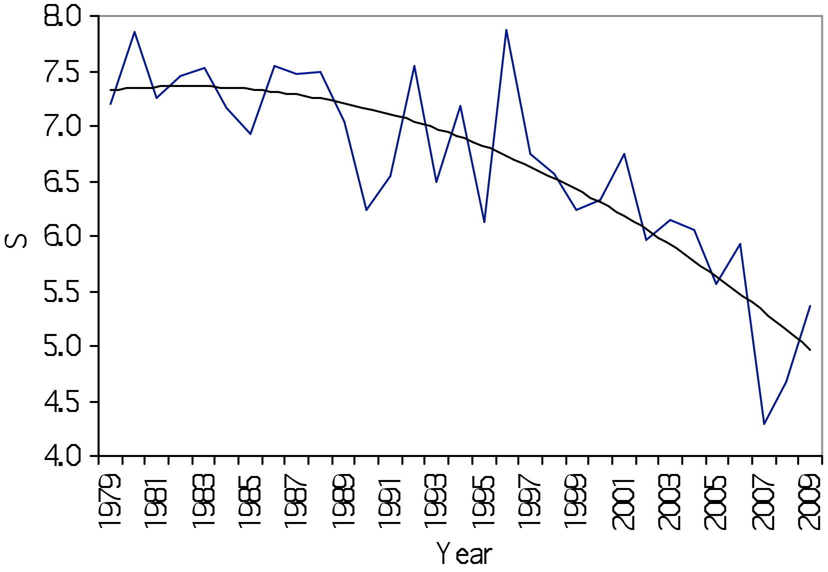


Figure 4-16: Ice covered area (S) in Arctic in September (million square kilometers). Data from [NSIDC ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/Oct/N_9_area.txt

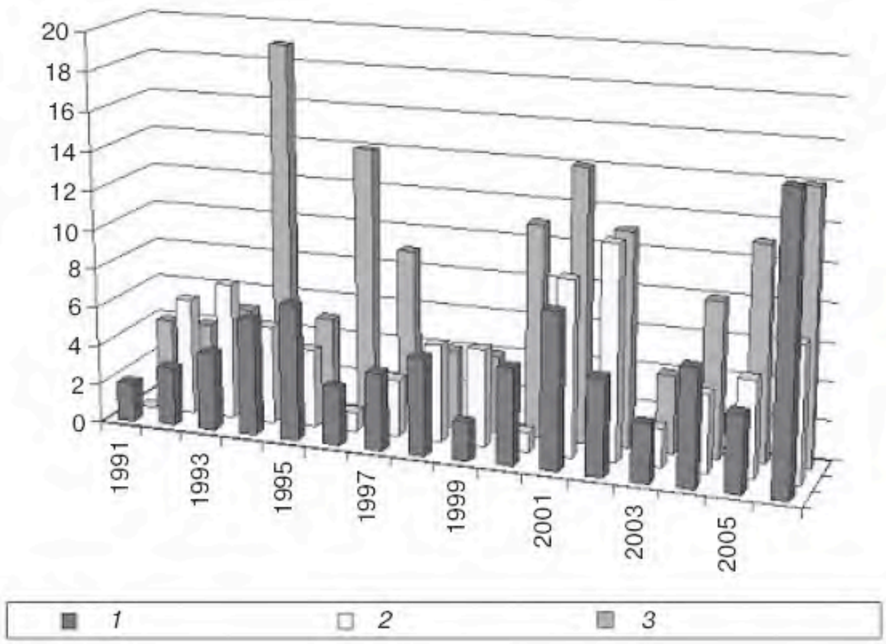


Figure 4-17: Annual change in the number of hazardous floods on rivers of Eastern Siberia, Western Siberia and the Far East 1991-2006

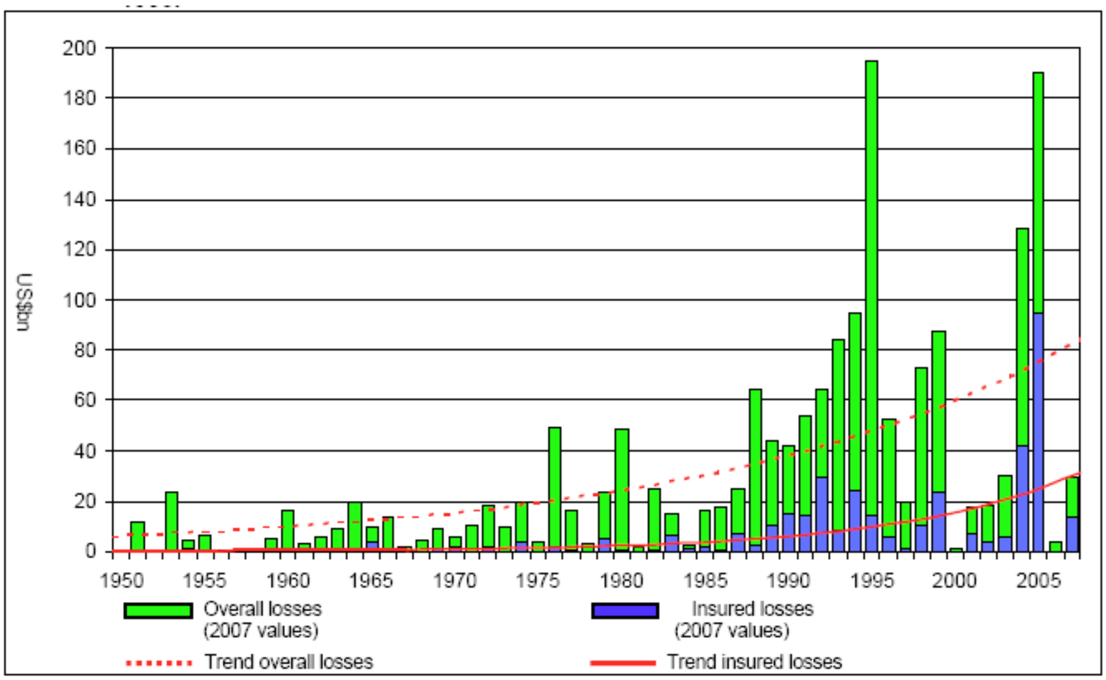


Fig 4-18: The overall losses and insured losses from natural disasters worldwide (adjusted to present values)

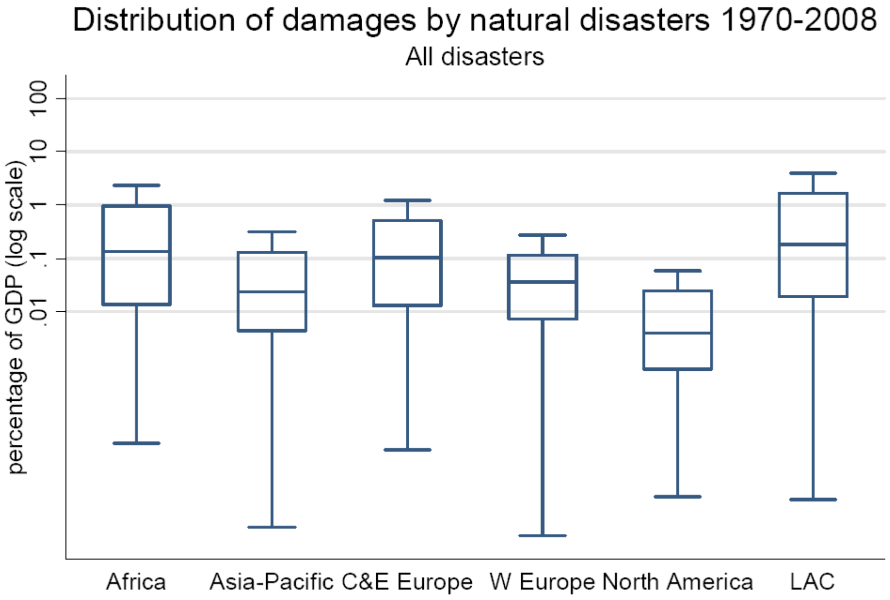


Fig 4-19: Distribution of Regional damages as a % of GDP (1970-2008)
Source: EM-DAT, WDI database, calculated by Cavallo, Noy (2009).