Chapter 19. Emergent Risks and Key Vulnerabilities

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Executive Summary

[to be developed]

19.1. Purpose, Scope, and Structure of the Chapter

19.1.1. Historical Development of this Chapter

The Third and Fourth Assessment Reports (TAR and AR4, respectively) each devoted chapters to evaluating the state of knowledge relevant to Article 2 of the UNFCCC (Smith et al 2001, Schneider et al 2007, see Box 19-1). The TAR sorted and aggregated impacts discussed in the literature according to a framework called *Reasons for Concern*

(RFCs), and assessed the level of risk associated with individual impacts of climate change as well as each category or "reason" as a whole, generally as a function of global mean warming. This assessment explicitly took account of the vulnerability of particular regions. AR4 furthered the discussion relevant to Article 2 by assessing new literature and developing criteria which might be used by policy makers for determining which impacts and vulnerabilities were *key*, i.e., meriting particular attention in respect to Article 2 (see Box 19-2 for definitions of Reasons for Concern and Key Vulnerabilities [KVs]). In addition, AR4 assessed emerging literature describing vulnerability pertaining to various aggregations of people (such as by ethnic, cultural, age, gender, or income status) and response strategies for avoiding key impacts. The Reasons for Concern were updated and the Synthesis Report (IPCC 2007) noted that they "remain a viable framework to consider key vulnerabilities". However, their utility was limited by several factors: the lack of a time dimension (i.e., representation of impacts arising from rates of climate change), the focus on risk only as a function of global mean temperature, lack of a clear distinction between impacts and vulnerability, and importantly, incomplete incorporation of the socioeconomic context, particularly adaptation capacity, in representing impacts and vulnerability.

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Box 19-1. Article 2 of the UNFCCC and the Copenhagen Accord

<u>Article 2</u>

OBJECTIVE
The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

<u>Copenhagen Accord (excerpt)</u>

To achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2 degrees Celsius, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change.

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Box 19-2. Definitions

Key vulnerability, key impact, key risk (extract from Chapter 19, WGII, AR4)
Many impacts, vulnerabilities and risks merit particular attention by policy-makers due to characteristics that might make them '*key*'. The identification of potential key vulnerabilities is intended to provide guidance to decision-makers for identifying levels and rates of climate change that may be associated with 'dangerous anthropogenic interference' (DAI) with the climate system, in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2 (see Box 19-1). Ultimately, the definition of DAI cannot be based on scientific arguments alone, but involves other judgments informed by the state of scientific knowledge.

Reason for Concern (summarized from Chapter 19, WGII, TAR)
"Reasons for Concern" may aid readers in making their own determination about what is a "dangerous" climate change. Each reason for concern is consistent with a paradigm that can be used by itself or in combination with other paradigms to help determine what level of climate change is dangerous. The reasons for concerns are the relations between global mean temperature increase and:

- Damage to or irreparable loss of unique and threatened systems
- The distribution of impacts
- Global aggregate damages
- The probability of extreme weather events
- The probability of large-scale singular events.

Emergent Risk
An emergent risk is defined as a risk which has only recently emerged in the scientific literature in sufficient detail to permit assessment, for example the potential impacts of geo-engineering (solar radiation management) on the monsoon. An emergent risk may eventually be identified as a *key risk* once sufficient understanding of it accumulates. Among the reasons for emergence of a risk is that its initial consequences have only recently been detected above the natural variability of the climate system, for example certain effects of ocean acidification on calcareous organisms. Risks may also arise gradually when they emerge from the interaction of phenomena in a complex system, for example the effect of populations shifting in response to climate change on the capacity of receiving regions to adapt to local climate changes.

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19.1.2. The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)

SREX (IPCC, 2011) provides additional insights with respect to the second "reason" (the risk of extreme weather events) and particularly the variations in capacities to adapt to such events between countries, communities, and other groups, and the limitations of implementation of these capacities. SREX emphasized the role of the socioeconomic setting and development pathway (expressed through exposure and vulnerability) in determining, on the one hand, the circumstances where extreme events do or do not result in extreme impacts and disasters, and on the other hand, when non-extreme events may also result in extreme impacts and disasters.

19.1.3. New Developments in this Chapter

With this framework already established, and a long list of impacts and key vulnerabilities enumerated and categorized in previous assessments, this chapter has two main objectives: first, to recognize the dynamic nature of our understanding by assessing *emergent risks* (see Box 19-2) such as those associated with impacts which have heretofore not been widely recognized in the literature. For example, since AR4, a large literature has emerged on response strategies which might be implemented under various interpretations of Article 2. The recognition (see Box 19-1) given to 2^0C in relation to Article 2 in the Copenhagen Accord spurred additional literature on response strategies corresponding to lower and much higher levels of warming. The second objective is to reassess and reorganize the existing framework (based on Reasons for Concern and Key Vulnerabilities) for evaluating the literature pertinent to Article 2 of the UNFCCC in order to address the deficiencies cited in section 19.1.1, particularly in light of the advances assessed in SREX as well as more recent literature.

In order to clarify the relative roles of characteristics of the physical climate system, like increases in temperatures, precipitation, or storm frequency, and characteristics of the socioeconomic systems with which these interact (usually summarized as vulnerability and exposure) to produce impacts, we rely heavily on a concept used sparingly in the TAR and AR4, *key risks*. Furthermore, we emphasize recent literature pointing to the *dynamic* character of vulnerability based on its intimate relationship to development.

We consider a variety of emergent risks within this framework, including for example, vulnerability to impacts arising from multiple interacting systems and stresses, indirect impacts, trans-boundary impacts, and impacts over longer distances. To cite one example that illustrates all of these properties, consider that climate impacts on agriculture, water availability, and sea level may cause populations to migrate. These shifts may lead to indirect impacts occurring at the new locations of settlement, which may be near the location of the original impact or quite distant. Such distant, indirect effects would compound the direct consequences of climate change at the locations receiving the incoming populations, and involve multiple physical and biological systems which interact, including impacts on ecosystems and species at the receiving locations which are then subject simultaneously to climate changes and consequences of an increased population.

19.2. Framework for Identifying Key Vulnerabilities, Emergent Risks, and Reasons for Concern

AR4 identified and assessed key vulnerabilities in order to specify risks related to the increasing levels of greenhouse gases and climatic change in the context of Article 2 (see Box 19-1). This and other conceptual frameworks to systematize, examine, and evaluate climate change related hazards (such as floods, droughts, storms, sea-level rise etc.), vulnerability, and risk have developed from different disciplines and have also varied over time (see e.g. IPCC SREX; Birkmann 2006a). The frameworks are contested to some degree; nevertheless, most of the concepts and the respective literature distinguish between the terms vulnerability, risk, impacts and hazards (e.g. IPCC SREX).

In the context of climate change, the term risk describes the potential outcome of the interaction of the vulnerable conditions of societies and human-environmental systems (these two terms are often shortened in this chapter to "social systems") exposed to climatic stressors (weather events, sequences of events, and mean and extreme behavior of climate). The concept of climate risk encompasses the probability of the occurrence of specific physical hazards arising from these stressors (see SREX and Box 19-2 for definitions), and the consequences of their occurrence in terms of impacts.

Recent literature indicates that risks in the context of climate change, such as risks related to health and well-being arising from, for example, droughts or heat waves (influenced by climatic change) or potential economic losses due to sea level rise, are not solely externally generated circumstances to which societies responds, but rather, the results of complex interaction among social systems, ecosystems, and hazards arising from the physical climate (Susman et al. 1983; Comfort et al. 1999, Birkmann et al. 2011). Impacts depend in turn on vulnerability and exposure of the communities, social systems and ecosystems and the services they provide, to the physical hazard. Vulnerability encompasses the concepts of susceptibility or sensitivity, and societal response capacities including adaptive capacity.

We define "key risks" as those risks that are considered large enough to be relevant to the determination of what constitutes "dangerous anthropogenic interference (DAI) with the climate system", under Article 2 of the UNFCCC (see Box 19-1).

Given that hazards influenced by climatic change interact with vulnerabilities of societies and social systems to produce climate change related risks, "key" impacts can be defined as the materialization of key risks as a result of the interaction mentioned above. We further differentiate impacts into two categories: a) first order impacts or direct physical or biophysical outcomes of climate change, such as glacier melting, ocean circulation changes, ice sheet disintegration, large scale forest-grassland transition, etc. and b) second order impacts that are specific manifestations of risk, measured in terms of harm and suffering, e.g. human mortality, monetized damages and losses as well as other metrics such as intangible losses (see IPCC SREX Chap. 2). These second order impacts arise from specific physical events (e.g., tropical cyclones), first-order impacts, or climatic trends (e.g., long term changes in the climate mean or extremes) and their interaction with vulnerable communities or a vulnerable human-environmental system. In contrast, the first order impacts are solely physical or biophysical manifestations of climate change.

While vulnerability refers primarily to characteristics of human systems directly exposed to climate change, such as the limited ability of human beings to adapt when affected by single or diverse hazards, exposure to hazards may also be indirect, for example, risk arising from mudslides generated by intense precipitation (UNDRO, 1980; Cardona, 1986, 1990; Liverman, 1990; Cannon 1994, 2006; Blaikie *et al.,* 1996; UNISDR, 2004, 2009; Birkmann, 2006b, Thywissen, 2006, Füssel and Klein 2006 and IPCC SREX 2011). Ecosystems or geographic areas can be classified as vulnerable as well, particularly if vulnerability of humans arises from impacts on ecosystem services.

Vulnerability is dynamic and context specific, determined by human behavior and societal organization, which influences the levels of exposure (e.g. urbanization of low laying areas) and susceptibility of people and livelihoods exposed, taking into account their response capacity (coping and adaptive capacities, see SREX chapter 1,2). Furthermore, human perceptions about risks and adaptation options influence adaptive capacities and decision making processes and consequently influence vulnerability of societies to climate change (e.g. Grothmann/Patt 2005; Rohmberg 2009; #cross reference needed to section 4.2.3 of our chapter#). Additionally, IPCC SREX stressed that consideration of multiple dimensions (e.g., social, economic, environmental, institutional, cultural) as well as different causal factors can improve strategies to reduce vulnerability to climate change (see IPCC SREX chap.2).

Extreme impacts and disasters, such as the outcomes of Hurricane Katrina and the 2011 flood disaster in Pakistan are worthy of special attention due to the scale of their impacts and the human suffering caused (IPCC SREX).There is a high confidence that behavior of the physical climate and respective hazards influenced by climate change only triggers disaster if the vulnerability of the exposed societies, communities or social systems is high. Identifying key vulnerabilities therefore also facilitates estimating disaster risks when coupled with information about the climate and climate change.

Overall, risk and its materialization in disasters or less extreme impacts is the product of the complex relationship between the physical and natural environment on the one hand and the society (its behavior, functioning, organization etc.) on the other. Ecosystem services as well as non-quantifiable attributes play an important role in the environmental dimension of vulnerability; many regions, communities or countries depend on a high quality of environmental services (productive soils, water, coastal resources for fishing, e.g. coral reefs) which can be severely affected by climatic change as well.

19.2.1. Frameworks and Assessments of Vulnerability

Vulnerability is a multi-dimensional phenomenon that changes over time and is spatially differentiated. Increasing urbanization of low-lying coastal areas, other demographic changes, trends in governance, and the process of human migration indicate that the exposure and vulnerability of people to certain hazards, such as sea-level rise, is dynamic. Likewise, characteristics of the physical climate, including mean and extreme properties and extreme weather events, such as storms, heat waves, and tropical cyclones to name just a few, are also dynamic, particularly under the influence of changing atmospheric levels of greenhouse gases and aerosols, in terms of their full range of characteristics as measured on multiple scales (SREX ch 3, AR4). The challenge here is to develop a framework for key vulnerabilities and emergent risks which advances beyond AR4 by capturing both aspects of this dynamism.

19.2.2. Criteria for Identifying Key Vulnerabilities and Risks

Broadly speaking, key risks are those potentially leading to highly negative consequences for societies, social systems, or unique ecosystems and species. Key risks are mainly the product of the interaction of climate-related physical hazards and impacts (e.g. glacier melting, landslides, etc.) with key vulnerabilities of societies and communities exposed. A risk would not be considered “key” if the climatic stressor or physical impact had a low likelihood and magnitude and would impact a social system with low vulnerability. Also vulnerability cannot be considered “key” if the consequences, taking into account different capacities of societies and exposed systems, are likely to be negligible (see Box 19-2).

The magnitude or other characteristics of the geophysical changes, such as glacier melting or sea level rise, are not by themselves adequate to determine key risks, since the consequences of climate change will be determined mainly by the vulnerability of the exposed society or the exposed social system or ecosystem. Key vulnerabilities embody a normative component because different societies might rank the various vulnerability factors and loss types differently. Recent literature underlines that vulnerability merits particular attention when the survival of communities or societies is threatened (ref).

Climate change will influence both the nature of the climatic stressors social systems and ecosystems are exposed to and also contribute to deterioration or improvement of coping and adaptive capacities of systems exposed to these changes. Consequently, many studies (Cardona 2010, Birkmann et al. 2011, Wisner et al. 2004) focus with a priority on the vulnerability of humans and societies as a key feature, rather than on the first order physical impact or the geophysical changes.

AR4 WGII Ch. 19 highlighted seven criteria that may be used to identify key vulnerabilities: Here we reorganize these criteria based on recent literature (refs) in order to distinguish those which are particularly appropriate to evaluating vulnerability as opposed to impacts. The criteria for identifying vulnerabilities as "key" used in the AR4 are: magnitude of impacts, timing of impacts, persistence and reversibility of impacts, likelihood (estimates of uncertainty) of impacts and vulnerabilities and confidence in those estimates, potential for adaptation, distributional aspects of impacts and vulnerabilities, and importance of the system(s) at risk.

Revised criteria for assessing key vulnerabilities used here distinguish between changes in the physical climate and associated biophysical impacts (like sea level rise), and vulnerability of social systems. The following seven criteria are used to judge whether vulnerabilities are key:

1) *Degree of exposure of the society, community, or human-environmental system to climatic stressors*. Exposure is an important precondition for considering a specific vulnerability as key. If a system is not at present nor in future exposed to climatic stressors, it is less important to consider its vulnerability to such stressors. The exposure to climatic stressors can be assessed in its spatial and temporal dimensions.
2) *Likelihood that exposure of societies, particular groups within societies, and social systems to a climatic stressor would cause major harm and losses (e.g., as determined by metrics discussed in AR4 WGII Chapter 19)*. Vulnerability is considered key when there is a high likelihood that structures and processes in societies and social systems create or would create conditions which allow a climatic stressor often in combination with non-climatic stressors (see Füssel and Klein 2007) to cause major harm and suffering of a system exposed. This criterion can be made specific with relative vulnerability assessment of societies, regions, and groups (one region or society or group within these may be more vulnerable than another). For example sea-level rise will impact coastal communities and regions worldwide; however, groups, communities and regions most vulnerable are those that are highly exposed, and that have a high susceptibility and a low capacity to cope and adapt to these influences. In this regard recent literature indicates that low-lying areas and communities in developing countries with limited resources to adapt and a low awareness about climatic stressors are more vulnerable than regions and communities in highly developed countries that can afford the further strengthening of coastal protection systems that reduce the negative consequences of sea-level rise. On the other hand, particular groups in developed countries may also be highly vulnerable (e.g., certain groups of residents of New Orleans at the time of Hurricane Katrina, see AR4, chx). Criteria that might be used to assess such structures and processes encompass among other issues poverty and wealth status, demographic characteristics, and governance factors (see IPCC SREX), such as failed states or violent conflicts. This focus on relative vulnerability is highly important to improve the knowledge base for adaptation needs.
3) *Importance of the system(s) at risk*. Various societies and people in different regions and cultural contexts might view the importance of systems differently. However, the identification of key vulnerabilities is less subjective when it involves those systems that are crucial for the survival of societies and the key ecosystem services on which societies depend. Recent literature underscores that high vulnerability arises particularly in the context of cascading risks and indirect threats, where the breakdown of systems in one region cause large scale negative consequences for other societies or systems.
4) *Ability of social systems to cope with the stressor within existing capacities*. Coping – although a contested concept - refers primarily to capacities that are available here and now to reduce the negative impacts of climatic stress on communities or human-environmental systems exposed. Coping in this way is part of the formula that determines vulnerability at any one moment in time. Coping also connotes the protection of the current system and institutional settings (see Birkmann, 2011) rather than improving these to increase capacities against climate risks (SREX, chapter 1.4).
5) *Ability of social systems to build adaptive capacities to deal with the changing environmental and climate conditions in the future*. The capacity of social systems to build adaptive capacities is a key issue when assessing vulnerability (IPCC 2007, AR4). Adaptation is a continuous property, with levels of adaptive

capacity changing over time. Adaptation in contrast to coping denotes a longer-term and constantly unfolding process of learning, experimentation and change that alters vulnerability. Adaptation includes acting to shape all aspects of vulnerability and is manifest through the systems and outcomes of learning – planned and spontaneous, pre- and post-disaster (Pelling, 2010). This understanding of adaptation is commensurate with the emerging consensus from climate change literature (see Kelly and Adger, 2000; Yohe and Tol, 2002; Pelling, 2010) where coping describes actions taken within existing constraints (including vision and knowledge), while adaptation signifies expanding the boundaries of those constraints, for instance, through institutional changes.

6) *Persistence of vulnerable conditions and degree of irreversibility of negative changes*. Vulnerabilities are considered key when they are difficult to alter and thus have high persistence as well as a high potential to interact with a hazardous event to produce irreversible negative changes. This is particularly the case when the vulnerability is high and the capacities to cope or adapt are low. In this way, social-ecological systems (coastal communities dependent on fishing or mountain communities depending on specific soil conditions) may reach a tipping point that would cause a partial or full collapse of the system exposed (ref).
7) *Presence of conditions that make societies highly susceptible or sensitive to cumulative stressors in multiply-interacting systems (indirect impacts, impacts generated by geographically remote causes, etc.)*. Societies which are vulnerable to collapse (as described in preceding paragraph) or ecosystem services that cannot be replaced or systems where redundancy is lacking are more vulnerable than those societies that cope effectively or those ecosystem services that can be quickly restored. Defining key vulnerabilities regarding various societal groups (as above in criterion #2), social systems or ecosystem services takes into account the contextual conditions that make these societies or exposed elements or groups highly vulnerable to cumulative stressors in multiple-interacting systems. Consequently, the vulnerability to cumulative stressors and vulnerability of multiple-interacting systems is not solely determined by the susceptibility of the system or group to the direct impacts of a hazard event, climatic stressor, or physical impact but rather determined by the susceptibility to cumulative stressors and multiple-interacting systems, including feedbacks among coping and adaptive capacity and climate change.

The following criteria outlined in AR4, Chapter 19 are retained for assessing biophysical impacts: *Likelihood and confidence, magnitude of the associated hazard, timing, persistence and irreversibility, and spatial distribution of the hazard (which affects the distribution of impacts across groups).*

19.2.3. Criteria for Identifying Emergent Risks

A risk can be called "key" when a hazard or biophysical impact of climate change (see criteria for impacts, above) interacts with a key vulnerability to generate major risks for humans or social or ecological systems that are pertinent to Article 2 of the UNFCCC (see Box 19-1; some risks associated with large scale discontinuities in the earth system, in the terminology of Reasons for Concern, e.g., disintegration of a major ice sheet, may be "key" because vulnerability to these is generally very high, by definition).

Emergent risks are those risks which have only recently emerged in the scientific literature in sufficient detail to permit assessment. Examples include risks for which the consequences have recently emerged (in the sense of being detected) above the natural variability of the climate system (see Box 19-2); risks linked to unforeseen feedback and response processes between climatic change, human interventions and feedback processes in natural systems; or new vector borne diseases or those diseases arising from partial break down of critical infrastructures, such as sewage systems that do not function properly.

The following provides an example of applying the above classification system:

- Key risks: The likelihood that the interaction of flooding events with vulnerability of a community would cause major harm. "Major" is defined by the various metrics discussed in 19.2.3.1.
- Physical impact: The increased frequency/intensity/duration of rainfall events that are likely to intensify flooding phenomena

- Vulnerability: The susceptible of a settlement or community exposed in a flood plain, lack of coping and adaptive capacities to deal with the direct consequences of flood events and to adapt to flood events in the long run.
- Emergent risks: Flooding risk emerges due to urbanization of vulnerable areas not historically populated, associated with complex interactions in multiple-interacting systems, e.g., human interventions, like the construction of dyke systems up-stream and the higher emergent risks for the newly urbanized downstream community.

Overall, the differentiation of direct physical changes, key vulnerabilities, and key risks allows an improved systematization of the different issues and factors that may be considered in the context of dangerous anthropogenic interference (DAI) with the climate system.

[INSERT TABLE 19-1 HERE
Table 19-1: An illustration of the systematization used in this chapter.]

Update of metrics of impact from AR4 and SREX
(Update to be based on metrics assessed in SREX and AR4 and more recent literature)

19.2.4. Identifying Key Vulnerabilities and Emergent Risks under Alternative Development Pathways

While some key risks, vulnerabilities, and physical impacts may have already emerged, many may only emerge with future climate change. Their emergence will depend in part on underlying socio-economic conditions, which can differ widely across alternative future development pathways. Some risks could be judged to be key under some development pathways but not others.

For example, both the likelihood and nature of physical impacts will be influenced by the pathway of future climate change, driven by emissions and other forcing such as land use change. These climate change drivers will themselves be influenced by the nature of socio-economic development, technical change, and policy. These factors will influence the rates and spatial distributions of emissions of greenhouse gases and aerosols, and of land use change. As a consequence, different development pathways will lead to different key risks because they affect the magnitude, timing, and heterogeneity of physical impacts of climate change (AR5 WGIII chapters).

In addition, development pathways influence the factors involved in identifying key vulnerabilities of human and ecological systems, including both susceptibility to impacts and adaptive capacity. The size or scale of populations, ecosystems, or economic sectors that are vulnerable to particular impacts will depend on population growth and spatial distribution, economic development patterns, and social systems. Which elements of these systems are most exposed to climate hazards, and which are considered most important, will depend on spatial development patterns as well as on possible changes in cultural preferences, attitudes toward nature/biodiversity, and dependence on climate-sensitive resources or services. The geographic or socio-economic heterogeneity of populations, and therefore the potential for distributional consequences, will be affected, as will the degree to which persistent or difficult to reverse vulnerabilities are built into social systems.

19.2.5. Assessing Key Vulnerabilities and Emergent Risks

(Link to the understanding of multiple-stressors /multiple interactions, etc., in other chapters)

19.3. Updating Key Vulnerabilities and Reasons for Concern

19.3.1. The Role of Adaptation and Alternative Development Pathways

As discussed in section 2, the identification of KVs, ERs, and RFCs depends in part on the underlying socio-economic conditions assumed to occur in the future, which can differ widely across alternative development pathways. Literature since the AR4 has begun to compare impacts across development pathways and also to compare the contributions of climate change and socio-economic development to impacts of various types. The relative importance of development and climate change varies by sector, region, and time period, but in general both are important to understanding possible outcomes.

For example, the impacts of climate change on food security and water stress have been found to be strongly dependent on socio-economic conditions. The effect of climate change on the number of people at risk from hunger generally spans a range across the four SRES scenarios of +/- 10-30 million, with the number rising to 120-170 million in some analyses based on the A2 scenario, which assumes high population growth (Schmidhuber & Tubiello, 2007). In all cases the effects of climate change were small compared to reductions in the prevalence of hunger driven by socio-economic development alone. Similarly, a global study of water stress found that population growth was the primary determinant of future water stress in a scenario in which global average temperature increased by 2 C (Fung et al., 2008). In a scenario with a 4 C increase, both climate change and population growth were important to determining outcomes.

Sea level rise impacts will also depend on development pathways, due to the effect of development on the exposure of both the population and economic assets to coastal impacts, as well as on the capacity to invest in protection (Anthoff et al., 2010). A study of Europe found that socio-economic development dominated coastal impacts over the first half of the 21st century, while over the second half both sea level rise and development were important (Hinkel et al., 2010).

Assessments of the impacts of extreme events have also evaluated the role of development pathways. Several studies argue that potential future damages from tropical cyclones are largely driven by socio-economic changes such as growth in population and wealth, and much less by the climate change signal itself (Bouwer et al., 2007; Pielke Jr., 2007). Flood risk in Europe has been shown in some cases to be as sensitive to assumptions regarding future land use and distributions of buildings and infrastructure as it is to the climate change scenario assumed (Bouwer et al., 2010; Feyen et al., 2009). Studies concluded that climate change was the dominant driver when particular aspects of socio-economic development, such as buildings and infrastructure, were excluded from the analysis (Linde et al., 2011) or when biophysical impacts such as stream discharge, rather than its consequences, were assessed (Ward et al., 2011).

With few exceptions, most ecosystem impact studies do not account for changes in future socio-economic conditions (Warren et al., 2011). A study of land bird extinction risk found some sensitivity to four alternative land use scenarios, but risk was dominated by the climate change scenario (Sekercioglu, 2008).

Some studies have not accounted for future socio-economic change, but have evaluated the vulnerability of sub-groups of the current population to climate-related stresses, showing that socio-economic conditions are a key determinant of risks related to climate volatility (Ahmed et al., 2009), exposure (Diffenbaugh et al., 2007), and storm surges (Dasgupta et al., 2009). Assessments of environmentally induced migration have concluded that migration responses are mediated by a number of social and governance characteristics that can vary widely across societies (Warner, 2010). These findings suggest that development pathways, which anticipate changes in these characteristics of societies over time, should be expected to influence the future risks of climate change.

Explicit assessments of the potential for adaptation to reduce risks have been less common, but when undertaken have indicated substantial scope for reducing impacts of several types. Assessments of the impacts of sea level rise have begun to incorporate the possibility of adaptation through investing in coastal protection and have indicated that widespread protection, and therefore a substantial reduction in impacts, can be an economically rational response for large areas of coastline globally (Nicholls and Cazenave, 2011; Anthoff et al., 2010; Nicholls et al., 2008). For example, a study of sea level rise impacts in Europe found that adaptation reduced the number of people affected by coastal flooding by a factor of 110 to 228, and total economic damages by a factor of 7 to 9 (Hinkel et al., 2010). Nonetheless, in some areas with higher vulnerability such as low island states and parts of Africa and Asia, impacts are expected to be greater and adaptation more difficult (Nicholls et al., 2011).

Similarly, the risk to food security could be reduced through policy and institutional reform, although most impact studies have focused on agricultural production (Ziervogel and Ericksen, 2010). A study of adaptation options in Sub-Saharan Africa identified substantial scope for adapting to climate change associated with a global warming of 2 degrees C, given substantial investment in institutions, infrastructure, and technology, but was pessimistic about the prospects of adapting to a world with 4 degrees of warming (Thornton et al., 2011; see also section 19.6.1).

Finally, the determination of key risks and vulnerabilities as reflected in the Reasons For Concern has not yet been distinguished across alternative development pathways. In the TAR, RFCs took only autonomous adaptation into account (Smith et al., 2009). An update based largely on literature assessed in AR4 concluded that the RFCs reflect more steeply increasing risk with global average temperature change in each category (Smith et al., 2009), but this conclusion was not based on a change in the assessment of future development pathways but rather on evidence of some impacts already becoming apparent, higher likelihoods of some biophysical impacts, and better identification of currently vulnerable populations.

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Box 19-3. Illustrating the Shared Socioeconomic Pathways

A new generation of socio-economic and climate change scenarios is under development intended to serve as a shared point of reference across research communities. Climate change scenarios are being produced by the climate modeling community based on a set of four Representative Concentration Pathways (RCPs; Moss et al., 2007) that vary widely in level and rate of change in radiative forcing. In addition, a set of Shared Socio-economic Pathways (SSPs) is being developed that would characterize a wide range of possible development pathways (Kriegler et al., submitted; Van Vuuren et al., submitted). The use of SSPs and RCPs (and climate model simulations based on them) to carry out scenario analyses is envisioned as having a matrix architecture, where each RCP could be used together with a range of SSPs, and similarly each SSP could be used in conjunction with multiple RCPs.

One of the key aims of the scenario matrix architecture is to facilitate research and assessment that can characterize the range of uncertainty in mitigation efforts required to achieve particular radiative forcing (or concentration, or emission) pathways, in adaptation efforts that could be undertaken in preparation for and response to the climate change associated with those pathways, and in residual impacts. All of these outcomes will be dependent on assumptions regarding future socio-economic conditions described in SSPs. To provide a basis for characterizing this uncertainty, SSPs are conceived of as being defined along two axes: socio-economic challenges to mitigation, and socio-economic challenges to adaptation. Socio-economic challenges to mitigation are defined as consisting of two components: factors that tend to lead to high *reference emissions* in the absence of climate policy because, all else equal, higher reference emissions makes that mitigation task larger; and factors that would tend to reduce the inherent *mitigative capacity* of a society. Socio-economic challenges to adaptation are defined as societal conditions that, by making adaptation more difficult, increase the risks associated with any given climate change scenario.

SSPs will include narratives, quantitative information that serves as input to integrated assessment and impact models, and other information – quantitative or qualitative – that will not be model inputs, but will help characterize the future in a way that will facilitate a wide range of studies at a variety of scales based on the SSPs. Although specific SSPs are still under development, the definition of the principal axes along which they will vary ensures that they will be very relevant to improving understanding of how alternative development pathways influence key risks, biophysical impacts, and vulnerabilities.
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19.3.2. Dynamics of Vulnerability

The literature provides increasing evidence that structures and processes that determine vulnerability, such as social, economic, environmental, institutional as well as cultural issues, are dynamic and spatially variable. The recent IPCC SREX report states with high confidence that the vulnerability of communities or human-environmental systems exposed to climatic stressors and physical impacts is characterized by dynamics that are influenced by socioeconomic trends, such as demographic changes, urbanization and governance processes (IPCC 2011).

For example social vulnerability increased over time in the United States in some areas due to socio-economic status, race-ethnicity and density of population and had, for example, a direct influence on the vulnerability of people exposed to the Hurricane Katrina disaster (Cutter and Finch (2007), where 1330 death occurred, with about 71% affected in Louisiana older than 60 years and about 47% older than 75 years (see in detail McCann 2011). Additionally, the Report to the US Congress (ref) estimated that 88,000 persons aged 65 and older were displaced by Hurricane Katrina. Thus demographic changes as well as changes in the strength of social-networks (social isolation of elderly in modern societies) and physical abilities to cope with such extreme events modify vulnerability over time and space (see e.g. Khunwishit 2007; Birkmann et al. 2011). In addition, population dynamics, such as population growth, migration e.g. from Latin America and Asia and urbanization are key factors that have increased the exposure of people in the USA to extreme events and vulnerability to such events (Rodriguez et al. 2008). These studies underscore that vulnerability assessments should account for long-distance impacts and multiple-stressors that might increase the vulnerability of a community or nation, such as the role of migration processes. However, the role of migration as either a trend that increases vulnerability or that reduces vulnerability is contested. Some studies show that particularly in drought affected countries and communities or in post-disaster processes migration can also be a source of coping and adaptation in order to buffer climate related shocks and non-climatic stressors (see Krings 2002). In either case, the interaction among climate change, climate-driven migration (see section 19.5), and adaptation capacity provides an example of the dynamical nature of vulnerability.

Important dynamics of human vulnerability have also been observed in the context of the occurrence of extreme events and disasters. In some case, vulnerability is dynamic and context specific, for example, the Indian Ocean Tsunami where disaster as well as the disaster response and reconstruction process modified the vulnerability of coastal communities (Birkmann and Fernando (2008). Human vulnerability changes in different phases of crises and disasters, and factors that might determine vulnerability before the disaster might differ from those that determine vulnerability after it.

Governance processes, such as the access rights of people to important resources like water and land, are also a key driver of dynamics of vulnerability. The design of risk reduction and climate change adaptation strategies under different forms of governance influences the vulnerability of people and communities as well as social systems exposed to such stressors. Additionally, studies about the effectiveness of early warning systems to climatic stressors and natural hazards as well as regarding the strengthening of coping and adaptive capacities clearly indicate the importance of governance, which itself can change over time, in these processes (see e.g. Chang-Seng 2010).

19.3.3. Differential Vulnerability (Age, Gender, Income, etc.)

(Input from other chapters and recent literature)

19.3.4. Risk Perception

(To be expanded and connected to definition of KVs, ERs)

There is a high confidence that risk perception influences and shapes behavior in terms of risk preparedness and adaptation to climate change (IPCC SREX, Weber 2006, Grothmann XX). Factors that shape risk perceptions include a) interpretations of the threat, including the understanding and knowledge of the root cause of the problem, b) exposure and personal experience with the events and respective negative consequences (Grothmann xx), c) priorities of individuals, d) environmental values and value systems in general (see e.g. O'Conner 1999; Weber 2006; Grothmann XX).

19.3.5. Physical, Ecological, and Social System Thresholds and Irreversible Change

Components of the earth system may respond non-linearly to greenhouse warming, such that the way in which these features operate may be fundamentally altered. Such transitions have been assessed within the KV/RFC framework, particularly in the form of Risks from Large-scale Discontinuities. Some have been coined 'tipping points' (Lenton et al. 2009) and are reviewed in detail in AR5 WG1 Chxx section x.x.x. Since AR4, the literature on this type of risk has expanded. Hypothetical transitions include collapse of the AMOC/thermohaline circulation (Keller et al, Lenton et al, Zickfeld et al) large scale ice loss from Greenland and Antarctic ice sheets, substantial dieback of the Amazon and boreal rainforest, complete loss of Arctic summer sea ice, persistent changes to the El Nino-Southern Oscillation variability and magnitude, disruption of monsoons, release of methane from permafrost and from marine hydrates, and ocean anoxia. Since AR4, research on climate change induced forest loss has highlighted the potential for threshold behavior, with some models (Jones et al 2009) suggesting a threshold for widespread transition away from a humid tropical forest as low as 2C, whereas Lenton et al give 3 to 4 C for an Amazon transition. Other work has highlighted the potential for synergy between these processes and human activity (i.e. increased fire risk) (Cochrane et al. 2010). The amount of additional carbon that could be released from melting terrestrial permafrost is very large – one estimate suggested 1/3 of the current release rate of CO2 emissions from fossil fuel burning (Khvorostyanov et al 2008). Large amounts of methane have been observed venting from the sea floor (Shakhova et al 2010), which may or may not be a response to climate change. However a threshold for release of 'significant' amounts of methane may exist for only a 1C increase in local seafloor temperature (Archer et al 2009).

Where a projected change is considered irreversible, it may be considered more serious that those which might be reversed (see discussion in section 19.2). Some types of change are intrinsically irreversible, such as species extinction. Most of the aforementioned large scale discontinuities in the earth system are also likely to be irreversible, at least on human timescales, either because they involve rapid release of material (ice or methane) that has taken centuries to millennia to accumulate, or because of hysteresis in the system itself (as in the thermohaline circulation, ref). More fundamentally, the evidence suggests that increases in CO2 concentrations cannot be reversed on a 100-200 year timescale absent massive and possibly unrealistic intervention in the carbon cycle.(Matthews & Caldeira, 2008; Solomon et al 2009; and Frohlischer&Joos 2010) (x-ref WG1 on this topic).

In human systems, rapid, large scale change may occur due to accumulation of physiological, industrial, social stress (refs). Responses range from human migration, the collapse of industries, or potentially, conflict (refs). The effect of climate-related stress (Burke et al 2009; Bauhaug 2010; Burke et al 2010;Tol and Wagner) on civil conflict has recently emerged as a risk. Key vulnerabilities which may trigger such transitions include exposure to prolonged drought, which may induce the collapse of agriculture in a region, or induce migration to wetter areas (Warren 2010). Another such key vulnerability is exposure to coastal flooding which may induce the permanent relocation of island societies (eg Tuvalu (ref), Bangladesh (ref)).

19.3.6. Aggregate Impacts

This section assesses recent literature pertinent to the Aggregate Impact Reason for Concern.

19.3.6.1. Social Cost of Carbon

The social cost of carbon is defined as the net present value of the incremental damage due to a small change in carbon dioxide emissions. It is a measure of the benefit of slightly reducing emissions.

Tol (forthcoming) counts 311 estimates of the social cost of carbon, published in 61 papers. The estimates depend on many assumptions, including about population growth, economic development, greenhouse gas emissions, climate change, and its impacts. Furthermore, assumptions are made about the conversion of impacts to a common metric (typically money) and the aggregation of impacts over time (discounting), across countries (equity weighing) and between states of the world (risk aversion).

The distribution of best guesses of the social cost of carbon understates the true uncertainty. Tol uses each published estimate and the standard deviation of the entire sample to fit 311 probability distributions[1], and combines these to an overall distribution of the social cost of carbon.[2] The results are in Table 19-2.

[INSERT FOOTNOTE 1 HERE: Specifically, he uses a Fisher-Tippett distribution, the only two-parameter, right-skewed, fat-tailed distribution that is defined on the real line.]

[INSERT FOOTNOTE 2 HERE: The sample probability density function follows from addition, using weights that reflect the age and quality of the study as well as the importance that the authors attach to the estimate – some estimates are presented as central estimates, others as sensitivity analyses or upper and lower bounds. Addition (vote-counting) rather than multiplication (Bayesian updating) is used because individual estimates are mutually exclusive.]

[INSERT TABLE 19-2 HERE
Table 19-2: The social cost of carbon ($/tC); sample statistics and characteristics of the Fisher-Tippett distribution fitted to 311 published estimates, and to five alternative ways to split the sample.]

The uncertainty about the social costs of climate change is very large. The mean estimate is $177 per metric tonne of carbon, but the mode is only $49/tC. The mean is driven by some very large estimates. The social cost at the 95th percentile is $669/tC. At the same time, a quarter of the probability mass is below zero.

The large range is partly explained by the use of different pure rates of time preference. Table 19-2 extracts three subsamples. The sample mean social cost of carbon for the estimates with a 3 percent rate of time preference is $19/tC, while it is $276/tC for a zero percent rate of time preference. The variation in estimates is still large, however, particularly for lower discount rates.

The mean estimate of the social cost of carbon is $80/tC in the peer-reviewed literature, and $296/tC in the gray literature. The range of estimates is much larger in the gray literature. This suggests that the more dramatic estimates of the impact of climate change are of unconfirmed quality.

Table 19-2 further splits the sample into studies that corrected for the fact that a dollar to a poor woman is not the same as a dollar to a rich woman, and studies that simply added dollar estimates of the impacts in different countries. Although equity weighting almost always increases the estimate of the social cost of carbon, the mean estimate of the social cost of carbon is $177/tC with equity weighting against $168/tC without. Table 19-2 also splits the sample into studies that report the mean social cost of carbon (typically estimated using a Monte Carlo analysis) and studies that ignore uncertainty and report a best guess value. Again, one would expect that, since the uncertainty is large and right-skewed, the average mean would be greater than the average best guess. However, Table 19-2 reveals that the average social cost of carbon is $68/tC with uncertainty and $206/tC without. The reason for these unexpected results is that equity-weighting and uncertainty analysis are only done with the more sophisticated models, which tend to produce lower estimates of the social cost of carbon.

Table 19-2 splits the sample into studies from before 1995 (Pearce et al. 1996), between 1995 and 2001, and after 2001 (Smith et al. 2001). The mean estimate of the social cost of carbon fell from $299/tC in the early studies to $113/tC in the latest studies. The standard deviation fell from $522/tC to $153/tC. This suggests that estimates of the impact of climate change have become less dramatic over time. The falling uncertainty suggests progress in our understanding of the impacts of climate change.

Although Table 19-2 reveals a large estimated uncertainty about the social cost of carbon, there is reason to believe that the actual uncertainty is larger still. First of all, the social cost of carbon derives from the total economic impact estimates, the full range of uncertainty about which is not known. Second, the estimates only contain those impacts that have been quantified and valued – some of the missing impacts have yet to be assessed because they are so difficult to handle and hence very uncertain. Third, researchers of the social cost of carbon are a reasonably small and close-knit community who may be subject to group-think, peer pressure and self-censoring.

19.3.6.2. The Willingness to Pay for Climate Policy

Section 19.3.3.1 discusses the social cost of carbon, a measure of how much money should be invested in greenhouse gas emission reduction. There are, however, also estimates of people's willingness to pay for climate policy. These studies use stated preference technique. The interviewees assess the extent of climate change, its impacts, and its values. In the impact studies reviewed in Sections 2 and 4, many of the necessary assumptions are instead based on expert knowledge and model studies. Furthermore, the perceived value of climate policy depends not just on the seriousness of climate change but also on the design of climate policy. Nonetheless, comparing estimates of the impact of climate to the willingness to pay for climate policy provides a robustness test.

There are some estimates of the willingness to pay for climate policy that relate to a specific impact (Layton and Brown 2000;Riera et al. 2007). It is more appropriate, however, to consider all impacts of climate change, and hence all impacts of climate policy. (Cai et al. 2010;Cameron 2005;Lee and Cameron 2008) estimate the willingness to pay to avoid all future climate change. (Cameron 2005) finds that US households would be willing to pay about 4.5% of their income. (Lee and Cameron 2008) reach a similar conclusion: 4.8%. The average of the median estimates in (Cai et al. 2010) is 9.5% of income. For a sample of Harvard students, (Viscusi and Zeckhauser 2006) find an average (median) willingness to pay of 6% (3%) to avoid all climate change. This suggests that lay people are much more pessimistic about climate change than experts (cf. Table 19-1).

Climate change cannot be fully avoided. (Li et al. 2004) find that 50% of Americans are prepared to sacrifice 0.5% of their income for a Kyoto-like abatement policy. A quarter are willing to pay 5.7%. (Berrens et al. 2006) find an average willingness to pay of 3.5% of income for US households for a Kyoto-like policy. It would probably be much cheaper to implement such a policy (Manne and Richels 1999). Furthermore, as the impact of the Kyoto Protocol on climate change is relatively small, the perceived economic impact of climate change is much larger than expert estimates (cf. Table 19-2).

Turning to estimates at the margin, (Carson et al. 2010) find that 57% of Australians is prepared to pay a carbon tax of $79/tC on transport fuels. The average European, however, is willing to pay only $37/tC for a carbon tax on transport (Hersch and Viscusi 2006). The average (median) Harvard student is prepared to pay $332/tC ($210/tC) (Viscusi and Zeckhauser 2006). Harvard students aside, the amount that people are prepared to pay in carbon taxes is reasonably in line with estimates of the social cost of carbon.

19.3.7. Improved Representation of Extremes in Key Vulnerabilities and Reasons for Concern

From the initial application of KVs/RFCs framework in IPCC-TAR, it was recognized that change in global mean temperature (GMT) does not describe all relevant aspects of climate change impacts, such as rate and pattern of change and changes in precipitation, extreme climate events, or lagged (or latent) effects such as rising sea levels (Smith et al.,2001). Though risks from extreme climate events were considered as one of the five RFCs in IPCC-TAR (and also in AR4), they were treated in a rather simplified manner partially due to the limited availability of impact literatures considering the aspects mentioned above.

The literature on impacts analysis considering changes in extreme events has advanced since AR4 partially based on the improved availability of climate model outputs with higher spatial and temporal resolution, which will enable improved reflection of extreme outcomes in the KVs/RFCs framework. Similarly, incorporation of the effects of changes in climate variables which may behave quite differently from GMT (e.g. precipitation) into the KVs/RFCs framework may be handled with greater specificity due to these developments.

On the other hand, the recognition of the critical roles played by dynamic vulnerability as reflected in development status, exposure, adaptation and coping capacity, and resilience in responding to extreme events, elaborated in great detail in SREX, raises additional difficulties in revising and updating the “extremes” RFC (see section 19.7).

19.3.8. Extreme Impacts and Disasters

Vulnerability and exposure are key determinants of disaster risk. Whether an extreme event, such as a tropical cyclone or a flood or drought, can cause an extreme impact and in the worst case, trigger a disaster depends on the vulnerability as well as the capacities of the community or human-environmental system exposed (see sections 2.x and IPCC 2011). In addition to the improvement of methodologies and data for assessing vulnerability and risk to climate change related stressors, the examination of potential tipping points in humanitarian crises is essential (see e.g. Lynn et al. 2010) in order to understand how extreme weather events and gradual environmental changes in the context of climate change can trigger disaster. Newer studies (refs) stress, that particularly feedback processes within social systems are key concepts in the discussion of tipping points. Feedback processes can result in a series of small effects having an unexpected large impact for the system exposed to multiple stressors, particularly if effects are cumulative and push a system over a tipping point, here understood as tipping points of social-ecological systems and thus different from and complementary to earth system and climate tipping points represented in the risk of large scale discontinuities (see e.g. Walker and Meyers 2004; Kinzig et al. 2006; Renaud et al. 2009). Consequently, extreme impacts on a system may be triggered by a single extreme event or a cascade of small events. Whether these shifts thereafter lead to a disaster depends on the vulnerability and adaptive capacity of the system exposed. Highly vulnerable systems and social groups are likely to face a higher disaster risk than systems exposed to the same stressor or hazard event(s) but which have low vulnerability. Studies in deltaic regions underscore that gradual changes such as salination or sea-level rise can cause extreme impacts and can lead to disasters if communities or ecosystems have limited abilities to increase their adaptive capacities over time and if development pathways increase the exposure and vulnerability to these hazards (ref).

19.3.9. Impacts and Vulnerability to Large Temperature Rise

Some impacts in addition to disasters may exceed adaptation capacity and thus merit special attention in the context of KVs and RFCs. Solomon et al. (2007) projected a temperature rise of 1.1-6.4 °C by 2100 relative to 1990 (or 1.6-6.9°C above pre-industrial levels). More recently, several authors have highlighted the potential for large, rapid temperature rise (Betts et al. 2011), particularly taking into account the potential for feedback processes which could not be quantified in the models used to produce the year 2100 projections (Solomon et al. (2007)). (Cross reference to WG1 on irreversible thresholds, and give the potential temperature rises that could occur as estimated by WG1). Most projections of climate change impacts are based on climate change scenarios corresponding to global mean temperature rises of up to 3.5°C relative to 1990 (or 4°C above pre-industrial levels) (Parry et al. 2004, Hare 2006, Warren et al. 2006, Fischlin et al. 2007, Easterling et al. 2007: more recent refs). There is a practical need for impacts assessment which considers the potential for larger temperature rises. In updating KVs, therefore we consider the new literature which covers these larger temperature increases, discussed in detail in 19.6.1.

Box: Dynamics of vulnerability
Figure: KVs, drawn from other chapters
Figure: Updated RFCs

19.4. Emergent Risk: Multiple Interacting Systems and Stresses

19.4.1. Limitations of Previous Approaches

Interactions between climate change impacts in various sectors and regions, and between these impacts and human adaptation in other sectors and regions, as well as interactions between adaptation and mitigation actions, are generally not included, or not well integrated, into projections of climate change impacts (Warren 2011). These interactions create emergent risks, potentially leading to identification of new key vulnerabilities. For example, an assessment of combined impacts of sea level rise, increased storm surge and natural and anthropogenic subsidence in deltas under a moderate scenario for sea level rise (Ericson et al 2006) revealed that over 6 million people would be at risk of enhanced inundation and increased coastal erosion in three megadeltas and 8.7 million in 40 deltas, absent measures to adapt. But this is one of the few studies to provide quantitative, global estimates of the combined effect of climate change impacts and other drivers. Many key interactions have not been quantified, for example, climate change induced biodiversity loss eroding ecosystem services which then in turn affects human systems dependent on those services. The large proportion of species at risk of extinction from climate change together with the effects of increased extreme events such as drought and forest losses due to fire, translate into such a risk. Examples include water purification provided by wetlands, purification of air provided by forests, protection of coastal areas from storm surges by mangroves and coral reefs, regulation of pests and disease, recycling of waste nutrients, and the removal of carbon from the atmosphere (Chivian & Bernstein, 2008). Impacts specific to extreme weather events are often ignored because many impacts projections are based only on changes in mean climate (Rosenzweig & Hillel 2008). Recent studies have revealed the importance of such interactions, for example the potential for increased crop damage due to increased prevalence of pest species (Petzoldt et al. 2006) and potential declines in crop yields due to climate change effects on pollinating species (Hillel & Rosenzweig 2008) simultaneous with its direct effects on yields through changing temperature, precipitation, and ambient carbon dioxide concentrations.

Human adaptation in a given sector can have consequences in another (e.g., a case of maladaption, see 19.4.2.5). For example, the building of dykes to protect towns can be to the detriment of associated natural ecosystems (Knogge et al 2004, xxxx et al. 2008) or adjacent settlements (Ericson et al. 2006); increasing irrigation to crops in response to a drying climate can exacerbate water stress in downstream areas such as wetlands, which themselves provide important water cleaning services. In addition to its benefits for crop productivity locally, agricultural intensification (World Bank, 2011) entrains negative impacts such as reduced biodiversity.

19.4.1.1. Issues of Scale

There is a distinct lack of harmonized, multi-scale analyses which link global, regional and local/city scale scenarios or issues. Hence, studies which attempt to quantify climate change impacts globally or within regions, are by nature broad brush approaches and cannot capture the diversity of impact of diverse magnitudes which may be found on a smaller geographic scale. For example, the climate in a large area may become generally unsuitable, but there may still be valleys where the crop can still be grown; whilst an area that appears generally suitable may have pockets of non-suitability. Such detail is not easily assessed because it is difficult to capture with current model resolution and downscaling techniques. Scale is particularly important in areas with varied topography. [This relates in particularly to the issue of downscaling climate projections to small areas. Shoo et al (ref) have developed an approach based on the physical characteristics of the underlying topography.] When considering synergies and conflicts between climate change impacts and potential adaptation strategies in different sectors, a broad brush approach may provide an overall picture for a region, but not the detailed outcomes in each locality.

19.4.1.2. Non-Climate Stressors

When assessing climate change impacts, interactions with non-climate stressors need to be considered. One example that has been well-studied for many years is the interaction with population – if the human population increases significantly, the number of people potentially at risk from climate change impacts increases, *ceteris paribus* (Parry et al 200x). More recently, interactions with other drivers are being considered. For example, habitat loss makes climate change impacts on biodiversity more likely to result in increased extinction rates, since larger areas of contiguous habitat support relatively greater numbers of species by reducing edge effects (ref). In addition, if species attempt to adapt to climate change by moving, fragmentation can create impassable barriers between an area of suitable habitat that is no longer climatically favorable and one that is newly favorable (in prep, Berry et al UK scale study). A new assessment of agricultural land availability projects that by 2050 large areas will be lost to urbanization, desertification, sea level rise and increasing salt water intrusion resulting in reduction in crop suitable crops varieties (Foresight, 2011 *check scale and location*)

19.4.2. Types of Interacting Social and Biophysical Systems

19.4.2.1. Interactions in the Management of Water, Land, and Energy

One of the most important interactions affecting the well-being of humans and ecosystems and the level and rate of climate change, are those involving human management of water, land, and energy. These profoundly affect the amount of carbon which can be stored in terrestrial ecosystems, the amount of water available for use by humans and ecosystems, the viability of adaptation plans for cities or protected areas, and so on. Failure to manage land, water and energy in a manner which maximizes synergy among management strategies can itself greatly increase the vulnerability of local populations and/or ecosystems, and can exacerbate climate change impacts globally. New risks emerge from consideration of these interactions, which have generally not been considered in the literature until recently. New integrated modeling tools are being developed to consider these linkages (Wise et al 200x, Warren et al. 2010, ref from ERMITAGE project in prep).

An estimated 2,400 GtC is stored in terrestrial ecosystems, compared to approximately 750Gt in the atmosphere (Ravindranath and Ostwald, XXXX). An additional ~ 38,000 GtC is stored in the oceans (37,000 Gt in deep oceans, ~ 1,000 Gt in shallow oceans; Sabine et al. 2004). A large amount of the terrestrial carbon is stored in forest (~1,146 GtC) with around 30-40% in vegetation and 60-70% in soils. However, significant carbon stocks, especially soil carbon, are found in other terrestrial ecosystems including wetlands and peat lands; e.g. peat soil carbon has been estimated to be nearly 30% of all global soil carbon whilst covering only 3% of the land surface (AR5 WGI Ch.x).

Thus there is significant potential to reduce emissions and increase the sequestration of carbon from land use management activities, an estimated 0.5-4 $GtCO_2$-eq from forestry activities (REDD, afforestation, forest management, agroforestry), and 1-6 $GtCO_2$-eq per year for agricultural activities (AHTEG report, refs therein). Deforestation releases 1.5GtC into the atmosphere each year (ref WG1) whilst unsustainable forest management releases further carbon (ref). Some 18% of annual greenhouse gas emissions originate from deforestation and other land use change, and a further 10-12% from agricultural activity. A recent study (REF) estimated that if all tropical forests were completely deforested over the next 100 years and if it was desired to constrain global mean temperature rise to 2C above pre-industrial, emissions of fossil fuels would have to be reduced by 6-7% annually, well above rates considered to be realistic. The deforestation would add about 400 GtC to the atmosphere, increasing the atmospheric concentration of carbon dioxide by about 100ppm, and contributing to an increase in global mean surface temperatures of about 0.6 ^{0}C (Warren et al in prep). This estimate does not include the warming effect of black carbon released to the atmosphere by biomass burning. Degradation of natural grasslands, can be a large source of carbon loss since cultivated soils generally contain 50-70% less carbon than those in natural ecosystems. Degradation and loss of temperate and tropical peat lands is also a major source of greenhouse gas emissions, with an estimated 3 $GtCO_2$ (or 10% of global emissions) released each year by the drainage and conversion of peat lands to agriculture or forestry, and peat fires.

First-generation biofuel consumption has been projected to increase by up to 170-220% by 2020 and up to 250-620% by 2030 (IEA, 2009), with the larger numbers corresponding to the introduction of a limit of 450ppm for CO2 concentrations. Second generation biofuels are thought not to be commercially viable for large scale production until after 2020. Biofuels presently occupy about 2.2% of global cropland, whilst the area under cultivation itself is expanding at some 3.4 million ha/yr (FAO 2010) due to rising demand for food. Hence, such large projections for increase in biofuel production have profound implications for land use change. If such land use change removes

primary forest, its net contribution towards climate change mitigation may be small (estimate) or even negative. The potential scope of the impact is revealed in one study (Wise et al 2009) which considers a scenario leading to conversion of more than 40% of global land area to biofuel production by 2095.
Where rainforest is converted to oil palm plantations, or where land is converted to sugarcane ethanol production, emissions of the precursors of tropospheric ozone increase (Hewitt et al 2009, Cancado et al. 2006). Where biofuels displace nitrogen-fixing crops such as soybean, fertiliser application will increase, leading to increased N2O emissions and nitrogen runoff into rivers and oceans (Donner & Kucharik 2008).

The water requirements of many biofuel crops are substantial (Fargione et al 2010, Fingerman et al 2010) and hence there would be increased issues with water management, and with efforts to allocate water for domestic, industrial, agricultural and natural wetlands particularly where irrigation is required (find more refs). Biodiversity is reduced by about 60% in U.S. corn and soybean fields and by about 85% in Southeast Asian oil palm plantations compared to unconverted habitat (Fitzherbert et a 2008, Fletcher et al. 2010, Fargione 2010). In Brazil, biofuel expansion is likely to impinge upon the Cerrado, the Amazon and the Atlantic rainforest all three of which have high biodiversity and high levels of endemism (Lapola et a 2010). Concessions of large areas for biofuel production have been made in the Brazilian Amazon, Papua New Guinea, and Madagascar, all of which are biodiversity hotspots (Koh et al. 2009). The resultant loss of ecosystem services (Xref section 4.1) would impact on human populations. Traits that make a plant a good candidate for biomass production also make it a potential invasive species (Barney & Ditomaso 2008, Council for Agricultural Science and Technology 2007, Raghu et al. 2006).

Displacement of agricultural land for biofuel crops would influence world food supply and prices (Hertel et al. 2010, Searchinger et al. 2008, see section 2.x.x), as actually occurred during the food price crisis of 2007/2008 (Pimentel 2009), thus increasing risks of malnutrition. Some biofuel feedstocks such as wastes, residues, cover crops, and forest thinnings (Tilman et al. 2009) are not in competition with cropland. At the same time, displacement of food crops, in combination with reduced yields due to climate change impacts, would encourage farmers to increase yields through application of larger amounts of fertiliser, particularly in countries where there is a supply shortfall (Deryng et al. 2011) which in turn increases greenhouse gas emissions.

Land use change also has direct effects on local climate: for example, new urban developments caused an intensification and expansion of the area experiencing extreme temperatures, mainly increasing nighttime temperatures, by as much as 10 K. (Grossman & Clarke 2010).

There can be important interactions between global policies and land management which can either exacerbate or mitigation climate change. Thus an important finding since the fourth assessment report is the identification of the effect of extending the placement of a carbon tax (as a surrogate for the effect of a variety of policies) to carbon emitted from land use change. In economic model simulations in which taxes are only applied to fossil carbon, with a goal of limiting CO2 concentrations to 450ppm-550ppm, large scale deforestation of 50-xx% of natural forests occurs, with conversion of most natural ecosystems, in part due to enhanced biofuel production (Wise et al 2009, Mellilo et al 2009a,b), whereas when the tax is applied also to include terrestrial carbon, the area of forested land increases. Not only does such deforestation emit CO2 into the atmosphere, it also reduces the terrestrial carbon sink (Warren et al in prep., X-ref WG1). In contrast, old growth forests continue to accumulate carbon (Lussayert 200x). Model estimates of 21st century land use range from 16-xx% of the earth's surface converted for first-generation biofuel production. Such large increases in the cultivated area of the earth's surface, which currently stands as 12%, would greatly exacerbate emissions of N2O, enhancing warming (Searchinger et al 2008, Fargione 2010) Similarly, indirect land-use changes can overcome carbon savings from biofuels in Brazil (ref). *More generally biofuel use* can decrease or increase both GHG emissions and other air pollutants compared to fossil fuel use, depending on the circumstances (Fargione 2010; Plevin (2009). Finally, where biofuels displace fossil fuels, a rebound effect can occur, so that not all the reduction in fossil fuel use is realised (Fargione 2010, USEPA, 2010).

19.4.2.2. Interactions Involving Health Effects and Disease Emergence

Climate change will act through numerous direct and indirect pathways to alter the prevalence and distribution of diseases that are climate and weather sensitive. Principal concerns include injuries and fatalities as a result of severe storms and heat waves; changes in vector biology and disease ecology that impact infectious diseases; water and food contamination; increased pollen production leading to increases in allergic airway diseases; and respiratory and cardiovascular disease secondary to degraded air quality and ozone formation. Indirect effects, for which data and evidence to support projections are less available and uncertainties are greater, include mental health consequences resulting from population dislocation, and nutritional shortages related to changes in food production (Portier et al 2010).

One of the key impacts is an increase in heat-related morbidity and mortality subsequent to the increase in the severity, duration, and frequency of heat waves (Luber and McGeehin 2008). This, coupled with an aging (and therefore more vulnerable) population, and a global shift to urbanization will increase the likelihood of higher mortality from exposure to excessive heat (Knowlton et al., 2007). In addition to heat waves, climate change is projected to alter the frequency, timing, intensity, and/or duration of extreme weather events, such as hurricanes, heavy precipitation events, and floods (see WGI AR5 Ch x). The health effects of these extreme weather events range from the direct effects, such as loss of life and acute trauma, to indirect effects, including large-scale population displacement, damage to water and sanitation infrastructure, damage to the health care infrastructure, and psychological problems such as post- traumatic stress disorder (Frumkin et al 2008).

While the association between ambient air quality and health is well established, there is an increasingly robust body of evidence linking spikes in respiratory diseases to weather events and to climate change, so that this interaction is emerging as a key risk. In New York City, for example, each single degree (Celsius) increase in surface temperature has been associated with a 3% increase in same-day hospitalizations due to respiratory diseases, and an increase of up to 3.6% in hospitalizations due to cardiovascular diseases (Shao Lin 2009). The principal pathways through which such respiratory health outcomes will be exacerbated by climate change are through increased production and exposure to tropospheric (ground-level) ozone, smoke produced by wildfires and through increased production of pollen (D'Amato 2010).

Many of the same populations that are vulnerable to health effects from heat waves, show increases risk for negative heat effects from poor air quality, including: the very young and the very old, those with preexisting medical conditions, including respiratory and cardiovascular disease.

Projected changes in precipitation, temperature, humidity, and water salinity, are also likely to affect the distribution and prevalence of food- and water-borne diseases resulting from bacteria, overloaded drinking water systems, and increases in the frequency and range of harmful algal blooms (Curriero et al., 2001, Moore et al 2008). Climate change and increased climatic variability are particularly likely to affect vector-borne diseases such as plague, Lyme's disease, malaria, hanta virus, and dengue fever which exhibit distinct seasonal patterns and sensitivity to ecologic changes (Githeko et al 2000, Gage 2008, Parham et al. 2011 submitted).

19.4.2.3. Effect of Degraded Ecosystem Services [including Biodiversity Loss] on Economic Sectors

Some of the work on degraded ecosystems and economic sectors examines the cost of restoring ecosystem services. For example, interviewed households along the Platte River (US) showed a willingness to pay, in terms of increased water bills, an additional US$20 per month in order to improve five ecosystem services (Loomis et al, 2000), the total amount "paid" US$19 to US$70 million dollars greatly exceeding the estimated costs of improving degraded ecosystem services (US$1.13 to US$12.3 million). A meta-analysis of 89 studies looking at the restoration of ecosystem services found that restoration increased the amount of biodiversity and ecosystem services by 44 and 25%. However, even after restoration, the values in restored ecosystems were lower than in intact ecosystems (Rey Benayas et al 2009). Estimates of the current value of the ecosystem services of pollinators in the UK are UK430 million per year yet the study also noted that this is one of the services currently declining (UKNEA 2011). The same study found that the increase in woodland (with the reverse being a measure of the cost of degradation) was worth UK680 million per year in carbon sequestration value alone.

19.4.2.4. Interactions among Risk Perception, Human Behavior and Environmental/Biophysical Systems

[to be developed]

19.4.2.5. Convergence of Multiple Impacts: Hotspots

The coincidence of impacts in different sectors in the same region could have consequences that are more serious than simple summation of the sectoral impacts would suggest. Such synergistic processes are difficult to identify through sectoral assessment and apt to be overlooked in spite of their potential importance in considering key vulnerabilities. For example, a large flood in rural area may damage crop fields severely, causing food shortages (Stover and Vinck, 2008). The flood may simultaneously cause a deterioration of hygiene in the region and the spread of water borne diseases (Hashizume et al., 2008; Schnitzler et al., 2007; Kovats and Akhtar, 2008). The coincidence of disease and malnutrition can thus create a hotspot for health impacts, with the elderly and children most at risk.

Identification of hotspots could be achieved by overlaying spatial data on impacts in multiple sectors, but this cannot indicate synergistic influences quantitatively. For global analysis, integrated assessment models have been used to identify regions that are affected disproportionately by climate change (Fussel, 2010; Tol and Fankhauser, 2008, Kainuma et al., 2003; Bowman et al., 2006; Warren et al., 2008). Recent efforts attempt to collect and archive spatial data on impact projections and facilitate their public use. These have created overlays for identifying hotspots with web-GIS technology (Adaptation Atlas (Vajjhala, 2009). There are also efforts to coordinate impacts assessments based on shared future scenarios at various spatial scales (Parry 2004).

[Insert examples of coordinated regional/national/city assessment of climate change impacts and suggested hot spots from regional chapters.]

General equilibrium economic models (see chapter 10) may facilitate quantitative evaluation of synergistic influences. An analysis of the EU by the PESETA project evaluated sub-regional welfare loss by considering impacts on agriculture, coastal system, river floods, and tourism together in the CGE model and indicated the largest percentage loss in Southern Europe (Ciscar et al., 2011). It should be noted, at any scale, choices of sectors are strongly constrained by availability of data or evaluation methods and they are not comprehensive.

19.4.2.6. Maladaptation

Maladaptation refers to adaptation strategies that increase a population or sector's vulnerability to climate change. The IPCC Third Assessment Report defines maladaptation as "an adaptation that does not succeed in reducing vulnerability but increases it instead" (IPCC 2001, 990). More recent treatments of this concept refine this definition to an "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups" (Barnett and O'Neill 2010, 213). More generally, maladaptation occurs "where the human response actively undermines the capacity of society to cope with climate change or further contributes to the problem" (Niemeyer et al. 2005, 1443). Maladaptations can take numerous forms, but quite commonly the maladaptation results from a blinkered approach to reducing impacts in one sector or region without considering the consequences for others. Maladaptation can operate on different temporal and spatial scales, includes for example adaptation actions or policies that increase greenhouse gas emissions, those that disproportionately burden the most vulnerable, have high opportunity costs, reduce individual incentives to adapt, and set paths that limit the choices available to future generations. An assessment of potential adaptation actions in the context of interactions across multiple sectors and regions would identify potential negative impacts (Barnett and O'Neill 2010, 212). Lack of consideration of such interactions could cause new risks to emerge.

Most clearly identified are those adaptation actions in one sector that impact another sector within the same region (Warren 2011, 218). For example, water stress in Burkina Faso, Sudan and Egypt has encouraged dam construction to ensure water resource resiliency. Dam building has led to has damaged wetlands and stimulated the reproduction of parasites in lakes nearby human settlements, leading to schistosomiasis and malaria (Molyneux et al. 2008). In theory, process-based impact models represent one way to quantify these interactions, but only a few interactions have presently been simulated within models (Warren 2011, 235). Another way to assess maladaptative responses is to qualitatively examine social responses. For example, the incentive for individuals to cooperate may decrease if they perceive that public institutions are unlikely to increase their adaptive response. One method to examine how human responses to climate change may influence subsequent behavior is to analyze people's perceptions of various climate change scenarios in order to understand what drives their behavior (Niemeyer et al. 2005, 1444).

Figure: Where are the hotspots [drawn from regional chapters] (Kiyoshi/Rachel) (500)
Box: Examples from other chapters [limits to adaptation] illustrating 4.2.5 (George) (500)

19.5. Emergent Risk: Indirect, Trans-Boundary, and Long-Distance Impacts

(A detailed review of indirect economic impacts will be handled by Ch.10; this subsection will focus on one such example to illustrate the nature of this ER).

19.5.1. Indirect, Trans-Boundary, and Long-Distance Impacts of Climate Change

19.5.1.1. Trans-Boundary Water Stress

[to be developed]

19.5.1.2. Long-Distance Impact on Agricultural Yields: Food Trade Patterns, Prices, Malnutrition

Climate change impacts on agriculture can have consequences beyond the regions in which those impacts are directly felt. Climate change has already significantly offset technology-related increases in crop yields in the last 30 years in countries such as Russia, Turkey and Mexico (wheat) and China (maize) (Lobell et al (2011). In the next few decades, areas where crop yields are projected to decline such as sub-Saharan Africa and the Sahel may come to rely more strongly on imported food (Scmidhuber & Tubiello, 2007). Whilst some studies (Jaggard et al. 2010, other refs) conclude that in the next few decades, there may be increases in crop yields in temperate regions which may compensate in global terms for the losses in tropical regions (FAO, 2008), a recent empirical study suggests that these benefits may not be realized, based on indications that, to date, the positive effects of CO_2 fertilisation on yields and the effects of changes in precipitation and temperature have offset one another (Lobell & Field, 2007). Median projected temperatures from AR4 are higher than any year on record in most tropical areas by 2050, and regions such as the Sahel, the Ukraine and SW Russia have already experienced declines in food production due to high summer temperatures (Battisti & Naylor, 2009). Taken together, the evidence points to an increased risk (compared to the assessment in AR4) that significant crop yield declines will occur in tropical regions on relatively short time scales.

Furthermore, developing countries which have limited financial capacity for trade, and/or food distribution networks may be damaged by increases in extreme weather events (FAO 2008) leading to increased risk of malnutrition. Developed countries which currently enjoy imported foods from tropical regions that become affected by climate change, would see the prices of those commodities rise (refs). More generally, regional climate change impacts on crop yields would result in increased prices of food commodities on the global market (Lobell et al. 2011, Battisti & Naylor 2009). The World Bank (2011) reports that weather-induced yield losses which have occurred in the past 1-2 years have affected food prices in many countries, and while many of these may not be related to climate change, there is some specific evidence that climate change induced yield losses are already affecting food prices (Lobell et al. 2011). Pressure on land use for biofuels is likely to further exacerbate food prices (see section 4.2.1). On longer timescales, new techniques for assessing climate change impacts on agriculture (Schlenker & Roberts 2009) result in higher projections of yield declines compared to studies assessed in AR4: yield losses of 30-46% by the end of the century under a low emissions scenario, or 63-82% under a high emissions scenario. Separately, Warren et al (2011) highlight that 50% of the world's cropland is projected to become less suitable for cultivation over the same period. A recent report (Foresight, 2011) highlights the combined agricultural land losses expected in the next 40 years, due to desertification, erosion and sea level rise (the latter leading to increased salination)). The report does not estimate the percentage of agricultural land involved, but if large such, changes would further increase global food prices, increasing the risk of poverty and malnutrition (World Bank, 2011).

19.5.2. Indirect, Trans-Boundary, and Long-Distance Impacts of Adaptation

19.5.2.1. Human Migration

Human migration is one of many possible adaptive responses to climate change (Reuveny 2007). Regional climatic changes are one of many factors which have contributed to migration to urban regions as individuals seek work for the purpose of sending remittances home (ref). By pursuing economic opportunities in other regions, people build resilience to climate impacts by distributing risks of economic loss through income diversification and circular mobility patterns (Adger et al. 2002; Tacoli 2009). A number of studies have linked past climate variability to local and long distance migration. Migration from one region resulting in significant indirect, (and in some cases, long distance) impacts in another is an emerging risk of climate change

Several studies have discussed potential future migration resulting from climate change on a global or regional basis (Myers 2002; McLeman and Smit 2006; Stern 2007; Warner 2009), including some global estimates of very large flows (Myers and Kent 1994). One study projects a future Mexico-US immigration under moderate warming scenarios of 1.4-6.4 million additional people (Feng et al 2010). Distinguishing the effect of climate from other influences that may simultaneously affect migration behavior, such as political, economic and household factors, and pre-existing networks (Munshi 2003), poses a significant challenge (Hunter 2005). Nevertheless, migration has been, and will likely be employed, as one strategy individuals and societies use to adapt to changing climatic conditions (McLeman 2011; Tacoli 2009).

Previous experience suggests that large-scale population displacement *within* vulnerable countries would be the predominant mode of migration (McLeman 2011) with, however important exceptions (Feng et al 2010) where international migration could be large. In areas with strong economies, rural-urban migration is currently predominant. It is, however, not the only form of movement that can occur inside countries. Rural-rural migration is another type that is particularly widespread in agriculture-based economies (Tacoli 2009). In Burkina Faso, temporary moves to other rural areas have increased as a result of a reduction in rainfall (Henry et al. 2004). Furthermore, the local and regional nature of past climate variability limits its utility as an analog for the effect of future global scale climate changes on migration. Climate change-induced drought has prompted both short-distance (Tacoli 2009) and long distance international migration, with the Mexican drought of the 1990s providing an example of the latter (Saldaña-Zorrilla S, Sandberg K 2009; Feng et al 2009).

Climate change induced sea level rise is a threat to individuals in small island states (cite). Migration will likely emerge as a dominant response to storm surges and flooding, but the extent to which this adaptation is employed in other areas will depend on whether governments respond to the challenge through strategies such as relocating people from highly vulnerable areas and conserving vulnerable ecosystems and key ecosystem services such as storm surge protection (Perch-Nielsen 2004) as opposed to so-called "hardening" such as building sea walls and storm barriers (Nordenson and Seavitt 2011).

Climate change-related migration may also aggravate pre-existing conflict or interact with other causes of social instability to cause conflict in regions receiving migrant populations (Reuveny 2007; Edwards 2008). . There is a range of views on the degree to which climate variability has been a contributing factor to past regional conflict and the potential role of future climate change in such conflict is also controversial (Burke et al 2009, 2010; Barnett and Adger 2010; Tol and Wagner 2010; Buhaug 2010).

19.5.2.2. Species Range Shifts: Consequences

One of the main adaptations of species to climate extremes and climate change is to move to areas where the climate is more suitable. Such shifts in species ranges have impacts even when transient (i.e., in response to climate variability), for example, conflicts between wildlife and cattle for diminishing water supplies. With climate change, these range shifts are having (refs) and will continue to have impacts as ecosystems shift leading to losses of some species and gains of others (Bradley et al. 2009). Past rates of dispersal are generally less than the projected rate of climate change. Therefore, as the climate becomes unsuitable for some species – potentially leading to degradation, the rate of dispersal is such that it will take longer for a new system to become established than an older system is lost. The challenge for natural resource managers will be to reassess the definition of what is an invasive species (Bradley et al 2009). As species undergo climate mediated range shifts, what once might have been considered an invasive species is actually an adapting species. Consideration needs to be given to what point movement should be facilitated versus inhibited.

19.5.2.3. Water Stress, Low Agricultural Yields

Local adaptation to water stress can include the construction of large dams, which can induce water shortages hundreds of miles downstream. Examples of such transboundary water conflicts already exist on the rivers Nile and Mekong (see section *5.1.1*). Hence climate-change induced water stress is likely to increase the number of these conflicts (ref water chapter, quoting areas in which there are projected increases in water stress and drought). Local adaptation to the effects of climate change upon agriculture can include irrigation, crop switching, or abandonment of cropping. Irrigation can induce water shortages downstream for humans and/or ecosystems, whilst changes in cropping patterns affect commodity prices as discussed in section *5.1.2*

19.5.2.4. Changing Land Use, Forest Loss

Changing land use can be an effective adaptation option for some climate change impacts. However, the change in land use as an adaptation poses new risks with indirect and distant impacts. For example, in order to utilize the opportunity of an increase in potential crop productivity in the area which is not cropland now, transformation of land use type would occur. While potentially increasing supply, such transformation may cause unfavorable or unintentional consequences such as changes in the carbon cycle, changes in the local climate through changes in surface energy and water balance, conflict over competing water demands, promotion of soil erosion, and loss of biodiversity and habitats. Those consequences constrain the feasibility of land use change as an adaptations strategy .

Few studies assess the global risks which will be posed by land-use changes conducted specifically for adapting to climate change impacts. Wise et al (2009) show that biofuel crops could occupy more than 40% of global land area by 2095 under some scenarios. General assessments of land use changes also reveal a variety of risks. Land-use change under different socio-economic scenarios is expected to cause terrestrial carbon loss in 21st century, which will compete with additional terrestrial carbon uptake caused by climate change and CO2 fertilization effect (Muller et al., 2007; OTHER REFs). Water demands associated with land use practices, especially irrigation, directly affect freshwater supplies through water withdrawals and diversions. Agriculture alone accounts for ~85% of global consumptive use. As a result, many large rivers, especially in semiarid regions, have greatly reduced flows, and some routinely dry up. (Foley et al. , 2005). Projections of global change impacts on biodiversity show continuing and, in many cases, accelerating species extinctions, loss of natural habitat, and changes in the distribution and abundance of species and biomes over the 21st century. Land use change, modification of river flow, freshwater pollution, and exploitation of marine resources are currently the most important drivers of biodiversity change and are projected to remain so over the coming century. (Leadley et al., 2010; OTHER REFs)

19.5.3. Indirect, Trans-Boundary, and Long-Distance Impacts of Mitigation Measures

19.5.3.1. Effects on Biodiversity

(link to and augment Section 19.4.2)

19.5.3.2. Effects on Human Systems

(link to and augment Section 19.4.2)

Box: Effects of migration

19.6. Other Emergent Risks

Additional emergent risks include those related to global mean warming exceeding 4C, the non-climate effects of CO_2, and to geo-engineering. With regard to the latter, we focus here on solar radiation management (SRM) because of the emerging literature on its unintended consequences.

19.6.1. Implications of a Global Annual Mean Temperature Rise of 4°C above Pre-Industrial Levels

An emerging literature now covers climate change impacts for a global annual mean temperature rise of 4°C above pre-industrial levels. Projections for the water sector include 840 million people globally experiencing an increase in water stress (Warren et al. 2010, Fung et al. 2011); increase from present-day 1%, to future 30%, of global land area experiencing drought at any one time (IPCC 2007); 50% flood-prone people exposed to increased hazard; flood-affected population rises to 544 million annually (as defined by those experiencing a present-day 1 in 100 year flood) (Kundzewicz et. al. 2010). In the agricultural sector, projections include 50% of land on which crops currently grown becoming unsuitable for cultivation (Warren et al. 2010); significant declines in crop yields (Lobell et al. 2011, other refs) particularly in tropical regions such as sub-Saharan Africa where there are limited adaptation options, resulting in threats to food security (Thornton et al 2011). At the same time a sea-level rise of x-y is projected by 2100 (Xref WG1 but current estimates 0.5-2m by 2100, or 0.47m in 2100 excluding accelerated ice discharge, Nicholls et al. 2007) and hence up to a 30-fold increase in population experiencing coastal flooding. Large risks to ecosystems including functional extinction of coral reef ecosystems (converted to algal mats) , risks of extinction to approximately 40% species studied globally, including losses of iconic species and associated ecotourism; disruption to functioning of major global ecosystems, (Fischlin et al 2007, CBD 2009,Warren et al. 2011); including Arctic and savannization of at least 50% of the Amazon rainforest; conversion of the terrestrial carbon sink to a source exacerbating climate change, large scale loss of forests via drying and fire (Lenton et al 2008, Zealowski et al. 2011) ; in particular a large increase in boreal and Mediterranean fire frequency; 50% of protected areas no longer able to fulfil objective; major widespread loss of ecosystem services worldwide; further mean acidification by 0.26 pH units (in addition to the present-day change of 0.1 units) (Orr et al. 2005, Bernie et al. 2010); risk of disruption to marine ecosystems; risk of localized ocean anoxia. One study examines the potential exceedance of human physiological limits in some areas (see 19.3.6) for a global temperature rise of 7C above pre-industrial (Sherwood & Huber 2011).

When considered together these combined impacts suggest a large scale emergent risk due to the movement of humans, agriculture and ecosystems, toward areas which remain sufficiently wet and cool (Warren et al 2011).

19.6.2. Ocean Acidification

Ocean acidification is defined as “a reduction in pH of the ocean over an extended period, typically decades or longer, caused primarily by the uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the oceans" (Feely *et al.*, AR5 WG1 Ch. 3). Ocean acidification is an emerging risk that, because it is thermochemically driven by the difference in partial pressures of CO_2 in the atmosphere and the ocean (Takahashi *et al.*, 2009), will continue to increase in magnitude as long as the atmospheric CO_2 concentration increases.

It is virtually certain that ocean acidification is occurring now (Dore *et al.*, 2009; Byrne *et al.*, 2010; Table 3.7.1 of AR5 WG1 Ch. 3) and will continue to occur in the future (National Academy of Sciences, 2010). The upper mixed layer of the ocean, which is in direct contact with the atmosphere, has experienced a decline in pH that is consistent with predictions of about 0.1 unit since the preindustrial (Feely *et al.*, 2004) and will continue to decline in response to atmospheric CO_2 forcing, e.g., by an additional 0.3 units once atmospheric CO_2 concentration reaches 800 ppmv (Feely *et al.*, 2009; Feely *et al.* AR5 WG1 Ch. 3). Ocean acidification of deeper layers is also occurring, but at rates dependent on ocean mixing (Caldeira and Wickett 2005; Ilyina *et al.*, 2009). Ocean acidification is a global phenomenon and without a decrease in atmospheric CO_2 concentration, it is irreversible.

Ocean acidification affects not only the pH of the ocean but also causes shifts in the carbonate equilibrium of seawater, that is, the relative proportions of the dissolved carbon compounds: CO_2 (carbonic acid and dissolved carbon dioxide), HCO_3^- (bicarbonate), and CO_3^{2-} (carbonate). Each of these compounds is associated with one or more biological processes including photosynthesis, calcification, reproduction, survival, growth rate, respiration rate, and nitrogen fixation.

Characterizing the risks of ocean acidification to marine organisms, populations, communities, ecosystems, and fisheries is limited by the complexity of interactions across these scales. Ocean acidification is a relatively new research area that has not yet amassed a large number of studies for quantitative risk assessment. A recent statistical meta-analysis of more than 70 laboratory studies across multiple taxa concluded that ocean acidification will have overall negative effects on organism growth, calcification, reproduction, and survival, but with a high degree of sensitivity among organisms (Kroeker *et al.*, 2010). Ocean acidification can also affect the availability of iron for marine photosynthesis, the rate of nitrogen fixation in several important cyanobacteria (Barcelos_e_Ramos *et al.*, 2007, Hutchins *et al.*, 2007, Kranz *et al.*, 2010, Kranz *et al.*, 2009, Levitan *et al.*, 2007) as well as the rate of denitrification (Beman *et al.*, 2011), and the chemical state and toxicity of some metals (Millero *et al.*, 2009). All of these processes can be considered emerging risks because of their effects on marine organisms, ecosystems, food webs, fisheries, and biogeochemical cycling (National_Academy_of_Science, 2010) (Figure 19-1).

[INSERT FIGURE 19-1 HERE
Figure 19-1: Emergent risks of ocean acidification to marine biological processes based on estimated likelihood that the process will be affected by ocean acidification and the magnitude of impacts to marine organisms. Calcification, for example, the best-studied process in terms of ocean acidification, is certain to be affected by ocean acidification and the magnitude of the impact on marine calcifiers is high. It is already a key risk, and is emergent in the sense that its occurrence has recently been detected. The height and width of the ellipses roughly indicate the uncertainties in the likelihood and magnitude of impacts, respectively. The dashed contour shows a line of equal risk (likelihood x magnitude); the area above and to the right of this line is broadly indicative of key risks. Ellipses that overlap the key risk area indicate that these emergent risks have the potential to become key risks in the future as understanding improves.,The uncertainty is based on impacts expected with atmospheric CO_2 levels of 2-3x predindustrial levels (560-840 ppmv).]

Marine calcification is considered a key risk based on numerous laboratory and field studies that indicate that ocean acidification poses both a strong likelihood of impact and a strong magnitude of impact to calcifiers and the ecosystems they support. Two recent studies of the marine ecosystem responses of ocean acidification due to natural carbon dioxide seeps (Hall-Spencer *et al.*, 2008; Fabricius *et al.*, 2011) document significant changes in community composition, biodiversity, calcification rates, and recruitment of corals at pH levels of 7.8, which is the expected pH once atmospheric CO_2 concentration reaches 750 ppmv. The latter study (Fabricius *et al.*, 2011) showed that coral reef growth ceased completely at pH levels < 7.7 (at atmospheric CO_2 concentration > 970 ppmv).

19.6.3. CO_2 Health Effects

The impact that elevated atmospheric CO2 has on plant species will affect health in two distinct pathways: through the increased production and allergenicity of pollen and allergenic compounds, and through the nutritional quality of key food crops. Not only will climate change alter the spatial and temporal distribution of several key allergens producing plant species (Shea 2008) but increased atmospheric CO2 concentration has been shown to stimulate pollen production. Ziska (2003) et al. found an association between elevated CO2 concentrations and temperature with faster growing and earlier flowering ragweed species (Ambrosia artemisiifolia) along with greater production of ragweed pollen, leading, in some areas, to a measurable increase in hospital visits for allergic rhinitis (Breton et al 2006). Experimental studies have shown that Poison Ivy, another common allergenic species, responds to atmospheric CO2 enrichment through increased photosynthesis, water use efficiency, growth, and biomass. This stimulation, exceeding that of most other woody species, also produces a more potent form of the primary allergenic compound, urushiol (Mohan 2006).

While the impact of increasing climate change and variability has been demonstrated to have an effect on crop production (Myers and Bernstien 2011), emerging evidence suggest an additional stressor: the impact of elevated levels of CO2 on the nutritional quality of important foods. A prominent example of the effect of elevated atmospheric CO2 is the decrease in the nitrogen (N) concentration in vegetative plant parts as well as in seeds and grains and, related to this, the decrease in the protein concentrations (Cotrufo et al., 1998; Taub et al., 2008;Wieser et al., 2008). Experimental studies of increasing CO_2 to 550 ppm demonstrated effects on crude protein, starch, total and soluble B-amylase, and single kernel hardiness, leading to a reduction in crude protein by 4 to 13% in wheat and 11 to 13% in barley (Erbs at el, 2010). Other CO2 enrichment studies have shown changes in the composition of other macro- and micronutrients (Ca, K, Mg, Fe, Zn) and in concentrations of other nutritionally important components such as vitamins and sugars (Idso and Idso, 2001). The declining nutritional quality of important global crops is an emerging risk that has the potential to broadly affect rates of protein-energy and micronutrient malnutrition in vulnerable populations. There is as yet insufficient information to assess whether this risk may become “key”.

19.6.4. Geo-Engineering (Solar Radiation Management)

[to be developed]

19.7. Assessment of Response Strategies to Manage these Risks

19.7.1. Relationship between Adaptation Efforts, Mitigation Efforts, and Residual Impacts Related to Key Vulnerabilities and Reasons for Concern

Response strategies to climate change can be thought of in broad terms as mixes of mitigation and adaptation that together will imply some degree of residual impacts. Evaluating the potential mixes of mitigation, adaptation, and impacts is an important task, made complicated by the fact that it requires joint consideration of alternative outcomes for both climate change and socio-economic development. Such an approach is complicated because socio-economic development pathways will influence future emissions, land use change, and therefore climate change, and in turn climate change will influence development pathways through feedbacks on social and economic systems, including policy responses.

Analyses are beginning to explore the potential mixes of mitigation, adaptation, and impacts that might occur, and how this mix could vary by climate change outcome, socio-economic pathway, region, and sector. Key risks and vulnerabilities for human-environment systems will vary along with these mixes, as will the nature of Reasons for Concern.

19.7.1.1.Variation of this Relationship across Climate Outcomes and Socio-Economic Pathways

Given a set of broad trends in drivers of socio-economic development, a particular scenario of integrated socio-economic and climate change outcomes will depend on the mix of mitigation and adaptation assumed to be undertaken. In the absence of mitigation, more climate change will occur and there will be a relatively high demand for adaptation. If more stringent mitigation is undertaken, less climate change will occur, and the need for adaptation will be reduced. Actual adaptation, and residual impacts, will be determined by the capacity to adapt (itself determined by characteristics of the development pathway) and the willingness and ability of individuals and societies to undertake adaptation efforts. Considering a single socio-economic pathway in Figure 19-2 illustrates this relationship across climate change outcomes.

[INSERT FIGURE 19-2 HERE
Figure 19-2: Illustrative relationship among mitigation efforts, adaptation efforts, and residual impacts across climate change outcomes and socio-economic development pathways. In general, limiting climate change to lower levels requires greater mitigation effort, implies a need for less adaptation, and smaller residual impacts. However these outcomes vary across socio-economic pathways. The “low challenges” pathway represents a world with low baseline emissions leading to warming of about 3 C in the absence of mitigation, low vulnerability and therefore less difficulty adapting, and relatively small residual impacts even at higher levels of warming. The “high challenges” pathway represents a world with high baseline emissions leading to about 5 C warming in the absence of mitigation, and high vulnerability. Thus, for the same climate change outcome (e.g., 3 C), the “high challenges” pathway implies substantially higher mitigation effort, adaptation effort, and residual impacts. [Note: Figure is preliminary and related to concepts the will appear in a forthcoming “conceptual framework” document being produced based on an IPCC workshop on socio-economic scenario development held in Berling, 2010. It may be possible to make this diagram more than just schematic by basing some judgments on existing literature (e.g. SRES-based) and on studies carried out within the new scenario framework that become available before the AR5 publication deadline.]]

Similarly, for a given climate change outcome, the mix of mitigation, adaptation, and residual impacts can vary widely depending on the socio-economic pathway assumed to occur. Reading across the three illustrative socio-economic pathways in Figure 19-2 for a given level of climate change illustrates this relationship. For example, a given climate outcome with a relatively low level of climate change will be more difficult to achieve through emissions mitigation, and more difficult to adapt to, if society follows a development pathway that has high challenges to mitigation and adaptation. Such a pathway may be carbon intensive, have limited availability of low carbon energy sources, and limited capacity to invest in technological development, making mitigation difficult. It may also have low investments in human capital and poorly functioning institutions, making adaptation difficult. It would be considerably easier to achieve the same level of climate change, and to adapt to it, in a world with a development path that favors rapid technological change, a preference for clean energy sources, has relatively low demand for energy, and well-functioning institutions.

The variation in mitigation, adaptation, and impacts across socio-economic pathways also has implications for characterizing the Reasons for Concern. RFCs are a means of aggregating some of the risks of climate change into a manageable number of categories. However, these risks are determined by both the physical impacts of climate change and the vulnerability of social and ecological systems to climate change stresses. RFCs already account for variation in risk due to the magnitude or likelihood of biophysical impacts, by expressing risks as a function of global average temperature change. However they do not distinguish the degree of risk across possible socio-economic futures. Figure 19-3 illustrates how risks associated with RFCs could vary depending on the development pathway. In general, low vulnerability pathways reduce key risks, while high vulnerability pathways increase them.

[INSERT FIGURE 19-3 HERE
Figure 19-3: Reasons for concern assuming alternative socio-economic development pathways. Low vulnerability pathways reduce key risks, while high vulnerability pathways increase them, since risk is dependent on both exposure to climate change hazards but also on vulnerability. An exception is the Risk of Large-Scale Discontinuities, which is the same across development pathways because this category is conceived of as a direct biophysical impact (not actually a “risk” as defined in section 19.2) that is independent of socio-economic conditions (Smith et al., 2009). Key vulnerabilities consistent with this diagram are the characteristics of human-

environment systems in each socio-economic pathway that render the system susceptible, and with limited ability to adapt to, the category of climate change stresses captured in each RFC. [Note: Figure is preliminary and schematic. If retained, the aim would be to base judgments illustrated in each diagram on assessment of the literature that differentiates impacts by socio-economic scenario.]]

The following example, pertinent to the RFC for Risk to Unique and Threatened Systems, illustrates the sort of sensitivity which the RFC framework currently does not incorporate (using the same scenarios as the AVOID studies, Warren et al 2011 in prep). This study showed that extinction risks are reduced globally by x-y% if stringent mitigation is applied, and again showed the avoided risks are greatest if global greenhouse gas emissions peak earlier.

The relationship between the peaking date of emissions and the avoided impacts arises simply from the practicalities of emission reduction (Xref WGIII) in relation to the limits that exist on the rate at which emissions can be reduced in the global economy, assuming a maximum emission reduction rate means that it is not possible to 'make up' for late peaking by reducing more rapidly later on. For example, to match the outcome of the scenario in which emissions peak in 2016 and are reduced at 2% annually, if emissions peak in 2030 emissions would have to be reduced at 3% annually to achieve the same consequence for global temperature change (Xref WGI, assuming they review this AVOID related study).

19.7.1.2. Relationship between Adaptation, Mitigation, and Residual Impacts in Regional and Sectoral Levels

For any particular combination of global climate change and socioeconomic futures, mitigation effort, and adaptation effort, residual climate change impacts will vary significantly across regions due to (a) differing levels of regional climate change, (b) differing levels of stock at risk in different regions (e.g. presence of unique ecosystems or the size of the human population exposed to impacts), and (c) differing sensitivities and adaptive capacities of humans, species or ecosystems in different regions. Similarly, residual impacts across sectors will differ significantly due to (a) different levels of sensitivity and (b) differing levels of adaptive capacity. Figure 19-4 gives an example of this regional and sectoral variation within a harmonized analysis on a global scale of the avoided impacts of climate change resulting from efforts to implement stringent mitigation (www.uk.avoid.net) (refs when published). The figure shows the impacts avoided by reducing greenhouse gas emissions from a SRES A1B scenario to one in which global greenhouse gas emissions peak in 2016 and are reduced thereafter at 5% annually. The impacts avoided range from 20-70% across sectors and x-y% across regions. They also show that avoided impacts are reduced when global emissions do not peak until 2030.

[INSERT FIGURE 19-4 HERE
Figure 19-4: Climate change impacts avoided by mitigation of greenhouse gas emissions under two different emissions scenarios.]

The limitation of current practice with respect to the full incorporation of adaptation is illustrated by this work in that some of the models did not include adaptation processes (e.g. water models), whilst others included a fixed set of adaptation policies which differed across regions (e.g. agricultural models). The model used to examine sea level rise considered a range of adaptation policies and hence the interaction between mitigation, adaptation and residual damages, showing how adaptation could greatly reduce the residual impacts (Nicholls et al 20xx).

Box: Case studies at the local/sub-national scale

19.7.2. Limitations of Response Strategies

Key risks, impacts, and vulnerabilities to which societies and ecosystems may be subject will depend in large part on the mix of mitigation and adaptation measures undertaken. However, mitigation and adaptation possibilities are not unlimited, implying that some degree of residual damages will be unavoidable.

19.7.2.1. Limits to Mitigation

[this section will be harmonized with WG3 in future drafts]

Assessment of maximum feasible mitigation (or lowest feasible emissions pathways) must account for the fact that feasibility is a subjective concept encompassing technological, economic, political, and social dimensions (Hare et al., 2010, UNEP Ch 2). Most mitigation studies have focused on technical feasibility, for example demonstrating that it is possible to reduce emissions enough to have at least a 50% chance of limiting warming to less than 2 C relative to pre-industrial (Edenhofer et al., 2010; Hare et al., 2010; den Elzen and van Vuuren, 2007; O'Neill et al., 2010; Clarke et al., 2009). Such scenarios lead to pathways in which global emissions peak within the next 1-2 decades and decline to 50-80% below 1990 levels by 2050, and in some cases exhibit negative emissions before the end of the century. In contrast, no model-based scenarios in the literature demonstrate the feasibility of limiting warming to a maximum of 1.5 C with at least 50% likelihood (UNEP, 2010).

However, most studies of technical feasibility include a number of idealized assumptions, including availability of a wide range of mitigation technologies such as large scale renewable energy, carbon capture and storage, and large scale biomass energy. Most also assume universal participation in mitigation efforts beginning immediately, economically optimal reductions (i.e., reductions are made wherever they are cheapest), and no constraints on policy implementation. Any deviation from these idealized assumptions can significantly limit feasible mitigation reductions (Knopf et al., 2010). For example, delayed participation in reductions by non-OECD countries made concentration limits such as 450 ppmm CO2eq (roughly consistent with a 50% chance of remaining below 2C), and in some cases even 550 ppm CO2eq, unachievable in some models unless temporary overshoot of these targets were allowed (Clarke et al., 2009), but not in others (Waldhoff 2011). Technology limits, such as unavailability of CCS or limited expansion of renewables or biomass makes stabilization at 450 ppm CO2eq unachievable in some models (Krey and Riahi, 2009). Costs may also become unacceptably high; for example, if low carbon powerplants and other infrastructure were limited to new installations (as opposed to replacement of existing stock), the maximum emissions reduction rate would be limited to about 3%/yr (Davis et al., 2010). Similarly, if the political will to implement coordinated mitigation policies within or across a large number countries is limited, peak emissions and subsequent reductions would be delayed (Webster, XXX).

These considerations have led some analysts to doubt the plausibility of limiting warming to 2 C with a reasonable probability (Tol, 2009; Anderson and Bows, 2008, 2011). "Emergency mitigation" options have also been considered that would go beyond the measures considered in most mitigation analyses (van Vuuren and Stehfest, 2009; Swart and Marinova, 2010). These include drastic emissions reductions achieved through limits on energy consumption (Anderson and Bows, 2011) or geoengineering through management of the earth's radiation budget.

19.7.2.2. Limits to Adaptation

New literature has emerged on the concept of limits to adaptation, whether they be theoretical physical limits, or financial or social constraints (Adger 2009), which is pertinent to several KVs and Reasons for Concern, particularly the risk of extreme weather events (Birkmann 2010a). Discussions are beginning on the nature of such limits, e.g. in relation to adaptation in cities (Birkmann 2010b). Limits to adaptation in relation to loss of water supplies as a result of glacier retreat are thought to be particularly problematic (Orlove 2009). Global warming of 7C would exceed a human adaptability limit to climate change due to heat stress (Sherwood & Huber 2011) by creating small zones where human metabolic heat dissipation would be impossible, and hence where lives would become dependent on air conditioning, and persons could not go outside. A global warming of 11-12C was projected to expose most of the human population to this level of risk. Since these estimates were based on extreme assumptions that the ‘people’ considered were doing all that they could to stay cool, by being dowsed with water in high winds and not working, a much larger fraction of the population could be at risk of life-threatening heat stress at lower, more realistic levels of global warming (see 19.3.10 and 19.6.1).

19.7.3. Avoiding Thresholds, Irreversible Change, and Large-Scale Singularities in the Earth System

Section 3.6 highlighted the reasons for concern related to non-linear changes in the earth system, whereby climate change might cause rapid and irreversible transitions in the global climate system. Mitigation efforts would reduce the risks of occurrence of these transitions, whereas adaptation, where possible (see 19.7.2.2) would reduce their consequences should they occur.

A number of studies have sought to identify levels of atmospheric greenhouse gas concentrations or global average temperature change that would limit the risks of occurrence of some of these transitions to a low level (refs). For example, Lenton et al. (2009) suggest that reducing the probability of an increase in temperature to 3 C above pre-industrial would limit risks of forest dieback, W. Antarctic ice sheet melting, collapse of the thermohaline circulation, and disruption of the monsoons and ENSO. However, the location of such thresholds is very uncertain (update from WGI assessment). A target for CO2 concentrations of 350 ppm has been suggested (Hansen) to avoid climatic tipping points such as the loss of major ice sheets and associated accelerated sea level rise, and abrupt shifts in forest and agricultural systems (Rockstrom et al. 2009, Foley et al. 2010), corresponding to a global mean temperature rise of Z1-Z2C (convert to GMT using WG1 info).

A number of analyses have focused on avoiding specific threshold events, in particular the weakening or collapse of the thermohaline circulation (THC/AMOC). A probabilistic analysis concluded that in the absence of mitigation, there is a one in three chance of triggering a THC collapse, and that constraining this likelihood to no more than 10% requires emissions reductions of 60% below business as usual by 2050 (McInerny and Keller, 2008). A deterministic analysis with best guess climate and economic parameter values found that a business as usual pathway would not lead to a THC shutdown even though CO2 concentrations would eventually rise to about 1000 ppm, but that under pessimistic parameter assumptions, emissions mitigation would need to begin within the next two decades to avoid an eventual collapse (defined as overturning rate reduced by more than 50%, Brucker and Zickfeld, 2009; Kuhlbrodt, 2009). In general, results are sensitive to uncertainty in climate and ocean circulation parameters (Zickfeld and Bruckner, 2008).

Another set of analyses has examined broader aspects of how the consideration of threshold events affects response strategies, particularly for mitigation. For example, response strategies could be greatly facilitated by observational systems and models that could facilitate prediction of the approach to a particular threshold; however, large uncertainties remain in the feasibility and requirements for such systems (Keller et al., 2008). Knowing that a threshold has been crossed, and that an irreversible change is inevitable, can also lead to reductions in emissions mitigation efforts and a shift of resources toward adaptation (Guillerminet and Tol, 2008). Some threshold impacts are not well correlated to levels of global average temperature change, leading to suggestions that additional metrics such as rates of climate change and spatial patterns of emissions and land use change be considered when formulating response strategies (Lenton, 2011; McAlpine et al., 2010).

19.7.4. Avoiding Social/Ecological Tipping Points

[to be developed]

19.7.5. Governance and Response Strategies

[to be developed]

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Table 19-1: An illustration of the systematization used in this chapter.

Direct physical impacts / hazards	**Key vulnerabilities**	**Key risks**	**Emergent risks**
Increasing precipitation and higher variability of rainfall patterns lead to increased flooding	People exposed in informal settlements People with little knowledge and capacities to deal with floods	Flood risks as a combination of the magnitude and intensity of key physical impacts and key vulnerabilities	Breakdown of critical infrastructure services, particularly in increasingly urbanized areas Conflicts between up- and downstream communities
Melting of the Greenland ice sheet and respective hazards due to sea level rise	People and social-ecological systems in low-laying coastal areas with low coping and adaptive capacities	Risks of flooding, and salination and higher threat of inundation and damage due to coastal storms	Combined impacts of sudden-onset hazards and gradual sea level rise poses new risks for societies living in coastal areas (e.g. urban and rural livelihoods) Potential push factors for large-scale migration in the medium and long-run

Table 19-2: The social cost of carbon ($/tC); sample statistics and characteristics of the Fisher-Tippett distribution fitted to 311 published estimates, and to five alternative ways to split the sample.*

	All	PRTP			Review		Equity		Uncertainty		Vintage		
		0%	1%	3%	Yes	No	Yes	No	Best	Mean	<1995	95-20	>2001
Mean	177	276	84	19	80	296	168	177	206	68	299	157	113
SD	293	258	93	18	109	442	200	316	332	93	522	227	153
Mode	49	126	48	10	26	70	65	44	55	23	43	48	42
P(SCC)<0	25%	10%	17%	11%	22%	24%	16%	27%	25%	22%	30%	23%	19%
33%	35	125	35	8	22	64	59	26	40	19	27	37	36
50%	116	212	71	15	57	192	117	112	135	49	175	106	81
67%	213	339	112	23	99	355	189	213	250	86	357	188	134
90%	487	646	204	44	206	814	478	489	573	177	916	429	273
95%	669	749	252	52	271	1165	614	690	777	233	1503	640	410
99%	1602	966	359	68	504	1925	789	1684	1676	422	2139	957	679
N	311	53	76	84	220	91	102	209	242	69	27	67	217

* PRTP = pure rate of time preference; review = peer-reviewed; equity = equity-weighted; uncertainty = best guess or mean value; vintage = year of publication

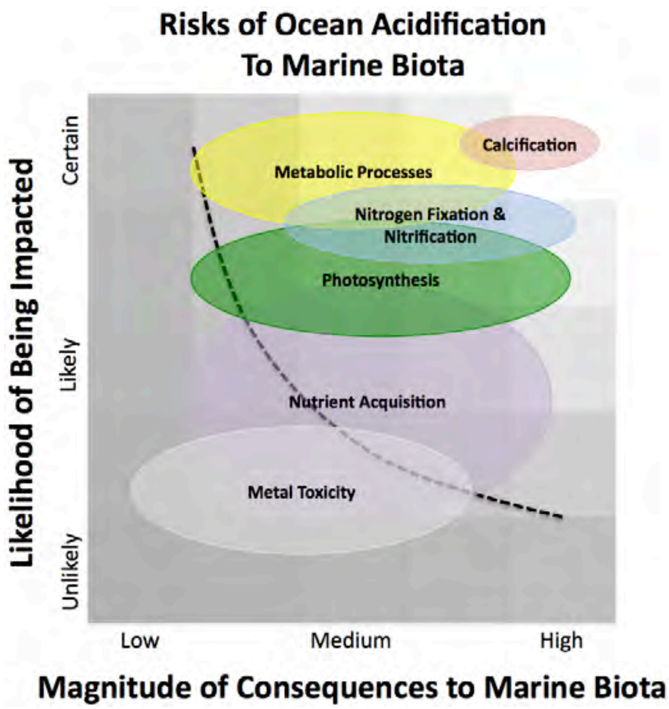

Figure 19-1: Emergent risks of ocean acidification to marine biological processes based on estimated likelihood that the process will be affected by ocean acidification and the magnitude of impacts to marine organisms. Calcification, for example, the best-studied process in terms of ocean acidification, is certain to be affected by ocean acidification and the magnitude of the impact on marine calcifiers is high. It is already a key risk, and is emergent in the sense that its occurrence has recently been detected. The height and width of the ellipses roughly indicate the uncertainties in the likelihood and magnitude of impacts, respectively. The dashed contour shows a line of equal risk (likelihood x magnitude); the area above and to the right of this line is broadly indicative of key risks. Ellipses that overlap the key risk area indicate that these emergent risks have the potential to become key risks in the future as understanding improves.,The uncertainty is based on impacts expected with atmospheric CO_2 levels of 2-3x predindustrial levels (560-840 ppmv).

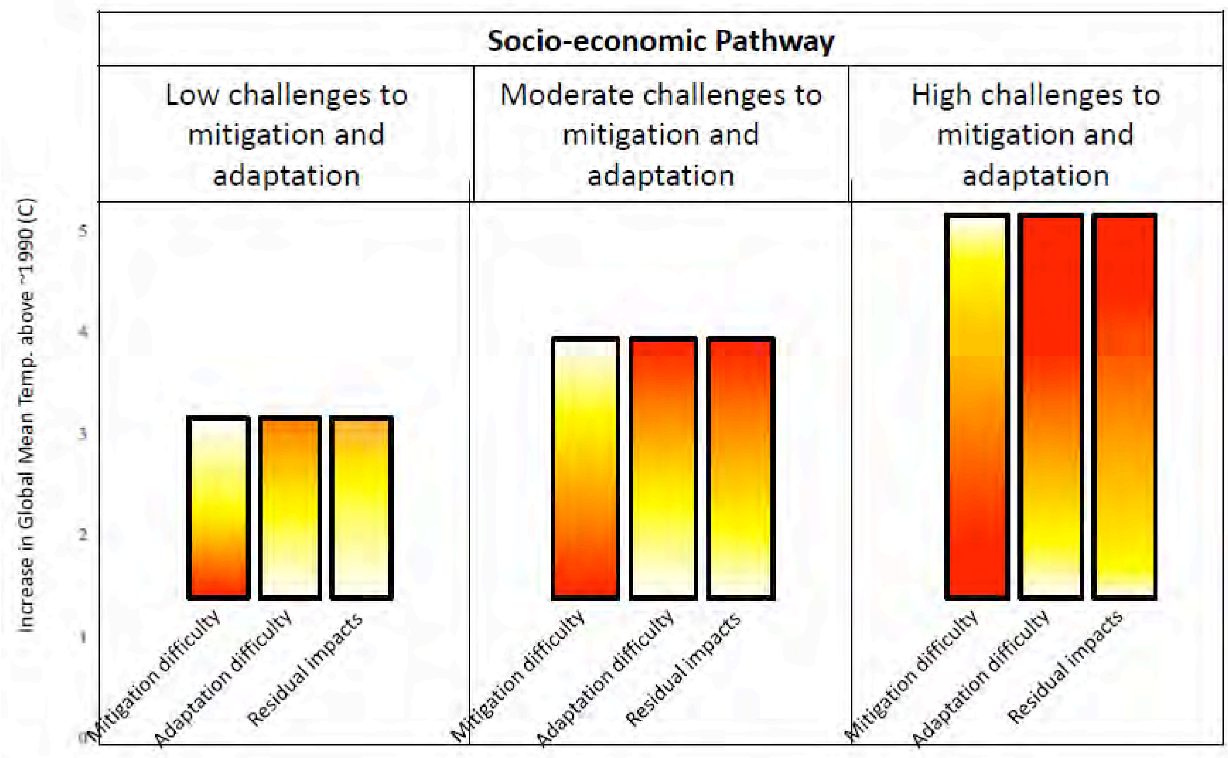

Figure 19-2: Illustrative relationship among mitigation efforts, adaptation efforts, and residual impacts across climate change outcomes and socio-economic development pathways. In general, limiting climate change to lower levels requires greater mitigation effort, implies a need for less adaptation, and smaller residual impacts. However these outcomes vary across socio-economic pathways. The “low challenges” pathway represents a world with low baseline emissions leading to warming of about 3 C in the absence of mitigation, low vulnerability and therefore less difficulty adapting, and relatively small residual impacts even at higher levels of warming. The “high challenges” pathway represents a world with high baseline emissions leading to about 5 C warming in the absence of mitigation, and high vulnerability. Thus, for the same climate change outcome (e.g., 3 C), the “high challenges” pathway implies substantially higher mitigation effort, adaptation effort, and residual impacts. [Note: Figure is preliminary and related to concepts the will appear in a forthcoming “conceptual framework” document being produced based on an IPCC workshop on socio-economic scenario development held in Berling, 2010. It may be possible to make this diagram more than just schematic by basing some judgments on existing literature (e.g. SRES-based) and on studies carried out within the new scenario framework that become available before the AR5 publication deadline.]

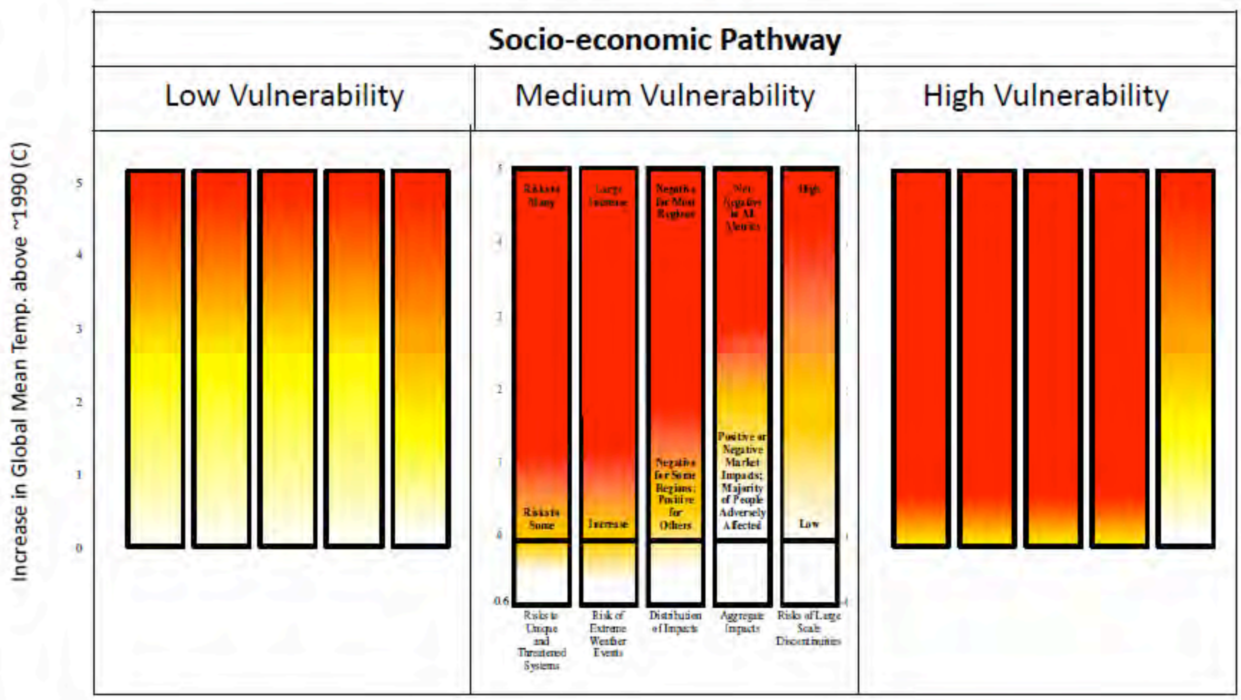

Figure 19-3: Reasons for concern assuming alternative socio-economic development pathways. Low vulnerability pathways reduce key risks, while high vulnerability pathways increase them, since risk is dependent on both exposure to climate change hazards but also on vulnerability. An exception is the Risk of Large-Scale Discontinuities, which is the same across development pathways because this category is conceived of as a direct biophysical impact (not actually a “risk” as defined in section 19.2) that is independent of socio-economic conditions (Smith et al., 2009). Key vulnerabilities consistent with this diagram are the characteristics of human-environment systems in each socio-economic pathway that render the system susceptible, and with limited ability to adapt to, the category of climate change stresses captured in each RFC. [Note: Figure is preliminary and schematic. If retained, the aim would be to base judgments illustrated in each diagram on assessment of the literature that differentiates impacts by socio-economic scenario.]

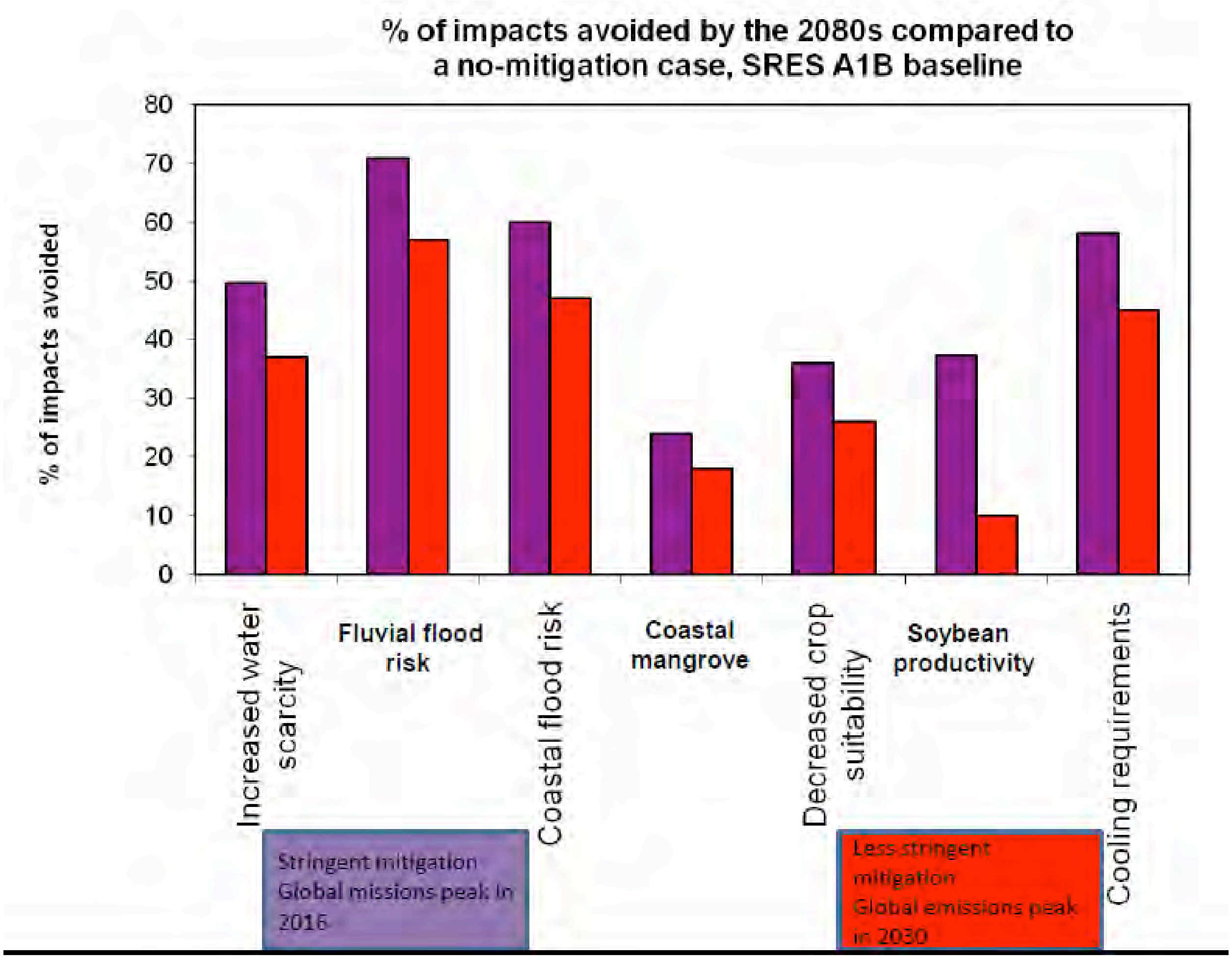

Figure 19-4: Climate change impacts avoided by mitigation of greenhouse gas emissions under two different emissions scenarios.