Chapter 21. Regional Context

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Executive Summary

[PLACEHOLDER FOR SECOND ORDER DRAFT: the text of the executive summary is preliminary pending the addition of information from the FOD version of other WGII chapters, and updates from the WG I SOD, especially where dependent on the completion of the CMIP5 archive]

Chapter 21 forms a juncture in the WGII report that comes between the thematic and conceptual chapters of part A and the more detailed regional chapters impart B. In addition this chapter provides an interface with the relevant regional messages found in WG I and WG III. The chapter provides an assessment for the practical application and translation of information into a regional context.

Context of Regions

The dilemma faced in past assessments is that the most effective treatment of regional aspects of the observed and projected physical climate, and its impacts and response options, may frequently be at odds with the scales at which political decisions need to be made. Climate change transcends political boundaries and is highly variable from region to region in terms of impacts and vulnerability. Likewise adaptation policies, options, and mitigation strategies are strongly region dependent and tied to local and regional development issues.

Consequently a regional treatment is integral and essential for a proper understanding of climate and the cross-scale issues. This chapter assesses a range of issues that act in concert with the climate at the regional scale, and include:

- large scale components of the climate system with regional consequence such as the cryosphere, oceans, sea level, and atmospheric composition
- climate change impacts on natural resource sectors, with regional contrasts in environmental conditions, and the livelihoods and human interventions that accompany them,
- emissions of greenhouse gases and aerosols and the regional expression of their sources and sinks,
- global scenarios of the major socio-economic, technological and land use drivers that affect anthropogenic emissions and also influence societal vulnerability at regional units of relevance to stakeholders wishing to interpret and apply them, and
- human responses to climate change through mitigation and adaptation at multiple levels of governance.

At regional scales policy makers face a dual challenge in achieving policy integration – vertically, at multiple administrative scales from global through national to local (multi-level governance), and horizontally, across different sectors (policy coherence). They must also navigate through myriad existing political structures and groupings (e.g. represented by the UNFCCC, regional, national and sub-national institutions). However, there are also emerging challenges for international policy making that may not be covered adequately by current international legal and humanitarian mechanisms, such as the opening up of the Arctic region, and environmental migration.

Likewise, cross-regional phenomena can be crucial for understanding the ramifications of climate change at regional scales, and its impacts and policies of response. These include global trade and international financial transactions, which are linked to climate change through a number of pathways: (i) as a direct or indirect cause of anthropogenic emissions, (ii) as a predisposing factor for regional vulnerability to the impacts of climate change, (iii) through their sensitivity to climate trends and extreme climate events, and (iv) as an instrument for implementing mitigation and adaptation policies. Migration is also a cross-regional phenomenon, whether of people or of ecosystems, both requiring trans-boundary consideration of their causes, implications and possible interventions to alleviate human suffering and promote biodiversity.

Baselines

The information used to establish the reference state for a system, and provide a baseline for calculating impacts must account for the variability of the factors influencing the system. In the case of climate factors at least 30 years of information, and often substantially more, is considered necessary. This includes baselines on variability over timescales of days to decades. When defining baselines a wide range of information is required as the systems being studied generally comprise interacting physical and human components influenced by climatic and non-climatic factors.

Significant improvements have been made in the amount and quality of climate data that are available for establishing reference states of climate-sensitive systems. These include new and improved observational datasets, rescue and digitisation of historical datasets, and a range of improved global reconstructions of weather sequences over past decades, in one case going back to 1880. Downscaling of coarse resolution global climate reconstructions and models can provide information which gets closer to the temporal and spatial resolution requirements for assessing vulnerability in many systems. Coordination of the assessment of this information is in its early days with initial results indicating models can have significant errors in their high resolution reconstructions of the current climate. Overall, the uncertainties inherent in model projections of regional climate changes have not decreased from AR4; in some cases, the addition of regional forcings (e.g. topography) have increased some uncertainties.

Non-climatic factors relevant to assessing a system's vulnerability general involve a complex mix of physical and socio-economic influences. Often these are continually evolving and thus generally only a reference point in time rather than a reference state over a period of time can be defined. There is significant new information on many of the physical non-climatic factors, especially those which are components of the new RCPs used in the CMIP5. Improvements in observations of other factors have also occurred but, as with climate information, in many cases the quality is regionally dependent and there are resolution deficiencies. The literature on characterizing vulnerability on sub-national and regional scales is mixed – but it is clear that there is significant variation in vulnerability due to variability in wealth, income, social factors, and access to governance.

Characterizing Future Change

The new developments subsequent to the AR4 relate principally to higher resolution climate scenarios, use of multiple scenario elements that go further than only climate change scenarios, and a new approach to constructing global scenarios as initiated by the development of representative concentration pathways (RCPs).

Projections of the future climate changes remain rooted in the GCM simulations, with studies dominantly still using the CMIP3 generation of GCMs for impacts and adaptation studies. The data from CMIP5 has yet to be widely adopted. Likewise, the downscaling to regional and high resolution still largely uses CMIP3, although significant new initiatives are underway based on CMIP5. Important uncertainties remain in their application in impacts and adaptation studies, as there continues to be a paucity of information on the relative merits and choice of different methods available for generating high resolution data.

The expanded use of multiple scenario elements beyond that of only climate scenarios still has unresolved issues. Among these are the downscaling of scenario elements, for example the economic activity information of RCPs, and the possibly inconsistencies introduced in using local sources for some scenario elements.

The advent of the RCPs likewise opens new territory; both the TAR and AR4 assessments were based around SRES. Whilst the RCPs embrace the range of scenarios found in the literature, they also include elements missing from the SRES set. Likewise, the current development of the Shared Socio-economic Pathways (SSPs) characterize a wide range of development pathways. However, at this stage of the AR5 most of the literature assessed for WG II remains based on SRES.

Increased attention is being placed on the role of multiple stressors in the number of studies, with many having a local or regional scope. This development has increased the need for a much wider range of data and wider range of projections for the wide range of stressors, across multiple spatial scales.

As impacts and adaptation studies have progressed, more applications of projections and scenarios to actual adaptation planning has occurred. Part of this development includes an increase in the number of scenarios used from global or downscaled models, either through by using more models or using ensembles of a set of models to explore the distribution of future impacts.

Credibility and Uncertainty of Information

For baseline information significant effort has been expended since the AR4 in improving the quality and homogeneity of climate observations. This work allows for a more accurate quantification of the amplitude of natural variability important for detecting trends or establishing impacts or vulnerability baselines. Complementing these developments are the availability of new and enhanced global reanalyses. The availability of multiple reanalyses further allows for the estimate of their uncertainty. Nonetheless, from the perspective of resolution, either temporal or spatial, there are important credibility issues in some regions where significant biases remain.

[Credibility and uncertainty of non-climatic baseline data is a placeholder pending material from WG3 and other WG2 chapter FODs]

Uncertainties of future climate remain centred on uncertainties over future climate forcing from emissions and concentrations, the climate system response to forcing, and the natural internal variability of the climate system. The likelihood of reducing uncertainty in future emissions and concentrations appears low, and future scenarios are mainly presented as having equal plausibility. Uncertainty in the climate system uncertainty has multiple sources in constrained understanding of the system dynamics, in how the system components are modelled, and in the parameterization of processes. Models are now more sophisticated that at the time of the AR4, and are more complete in the components of the climate system that are included. Nonetheless, important processes remain incomplete, for example the explicit modelling of ice sheet dynamics.

The models produce a range of projected futures, and for some variables and locations the sign of projected change may differ from one model to another. However, in many instances this indicates a lack of significant change compared to the natural variability for that region. The degree to which the model uncertainty can be reduced remains an issue. [to be discussed in more detail by WG I SOD and WG I FAQ]

The role of natural variability as a source of uncertainty is important as a function of the time horizon being considered and the spatial scale of interest. Recent work with large numbers of ensemble members has improved measures of natural variability.

[Credibility of scenario elements will be addressed in the SOD]

New Understanding on Climate Change: Physical System

Regional climate information in the AR4 were not comprehensive enough to provide a coherent picture of past and future regional changes with associated uncertainties. Improved regional scale information is now available. In addition, more targeted analysis of climate projections for impact assessment studies have been carried out. The leading messages from these developments include: [To be updated and developed after the WGI SOD]

- A strong regional variability of projected change is found for surface climate variables. Different indexes combining sets of climate variables and statistics indicate the emergence of various climate change hot-spots at different times in the future. Better process understanding is needed to increase confidence in the identification of climate change hot-spots.
- Broad regional patterns of late 21st century temperature and precipitation change projections, as well as changes in temperature and precipitation extremes, from the latest generation GCM simulations (CMIP5) are generally in line with previous projections available in the AR4.
- Preliminary analysis of decadal prediction experiments in the CMIP5 ensemble show that decadal predictability of unforced regional precipitation and temperature patterns over land is very low. Indications of some predictability of ocean temperatures of up to 10 years lead time is however found over some ocean basins
- Uncertainties and ranges of regional scale projections have not decreased from the AR4, in fact the effects of local forcings which can be represented with downscaling methods likely lead to an increase in uncertainties.
- A larger set of global and regional (both dynamical and statistical) model projections allow a better characterization of uncertainties than in the AR4, and more methods are available to produce probabilistic projections of changes for use in IAV assessment work.
- Projected changes in the oceans, sea level and cryosphere are also consistent, at least qualitatively, with previous estimates from the AR4 and with improved observations of recent past trends. Quantitative values of projected changes may however differ from the AR4 due to the availability of better models and larger ensembles, especially at the regional scale.
- Climate change is expected to substantially affect regional air quality, for example near surface ozone concentrations, however this effect also depends strongly on future emissions.

The regional specifics of these are explored in the chapter under section 21.4.1 and considers both large scale features processes, and continental scale assessment.

[To be updated and expanded when CMIP5 and CORDEX results become more available]

New Understanding on Climate Change: Mitigation

The derivation of the RCP's and the parallel process for scenario development has enabled the climate modeling community to consider explicit mitigation scenarios for the first time. Substantial regional information (0.5 degree global resolution) of economic activity, development trajectories, and emissions are available for analysis, but remain largely unexplored. The RCP's are known not to be unique pathways to the identified radiative forcing targets. Model to model variability of the IAM's used to generate the RCP's is also largely unexplored.

The importance of land-cover and land-use changes as an indirect response to meeting mitigation targets has been explored extensively since AR4. It is now clear that achieving targets without putting a price on carbon emissions from land-use has the potential to lead to very large reductions in forested area, and much higher overall costs for mitigation, compared to meeting the same targets while putting a price on all carbon emissions. Similarly, while substantial regional variation in the availability of technologies is known to exist, the differences in how these are represented regionally is largely unexplored.

A process (shared socioeconomic pathways, SSP's) has been initiated to identify shared assumptions and global scenarios for use in both mitigation and adaptation research. But although progress has been made, the vast majority of the impacts, adaptation, and vulnerability literature since AR4 continues to be based on the SRES.

Cross-Regional Phenomena

The variability of vulnerability across regions, and across subpopulations within regions is an area of active research, but methodological difficulties preclude general statements about the factors that control that variability, and how they might evolve in the future.

Trade and financial flows influence both vulnerability and adaptive capacity, and also the regionalization of emissions. At the same time, international and cross-regional financial instruments are being used to attempt to build adaptive capacity as well as mitigation capacity.

Human migration in reaction to climate-driven phenomena, or extreme weather events, is usually within nations, but under some circumstances, can extend across nations. The migration of ecosystems in response to changes in climate emphasizes the need for cross-regional cooperation of conservation and resource management institutions.

21.1. Introduction

This chapter has several goals that play a new role in the IPCC scientific assessments. It seeks to highlight how the thematic content of the first half of the volume has substantial regional variation and context, how regional differences compare to each other, and what issues transcend regional boundaries. It then sheds light on how those differences affect risk profiles, discusses the relevant outcomes of Working Groups's I & III, and assesses regional information about both non-climate Earth systems and the physical climate system.

To address these goals, the chapter focuses on four objectives:

1) It begins to identify the resources and regions that are subject to climatic risk, and identify the factors that contribute to different levels of intrinsic vulnerability, from decision-making institutions to baseline information and trends. The chapter summarizes the main features of commonality and differences among regions, and explores methodological concerns with how regions are identified, how we understand the different scales of regional decision-making, and which sectors are of particular interest, either because they are common across regions, or because their variation across regions is especially important.
2) It articulates the exposure factors of risk – what is our current understanding of how we represent global climate and its changes in regional terms – how do we do this for both climate trends and extremes, and how well do we understand the extent to which regional changes in baselines can be attributed to anthropogenic change.

3) It explores how regional stakeholders and institutions can think concretely about characterizing the future evolution of risk, so that the best science can be brought to bear on how that risk can be managed. Therefore, the chapter presents its best judgment on the science behind the challenge of regionalizing climate model output, and also on the science behind how regions would evolve in the absence of those risks, and how they would respond to different adaptation and mitigation actions.
4) It explores the connections between regions, both in terms of their underlying baseline conditions, in how they resemble or differ from each other, and in terms of how they affect each other through a range of other drivers – trade, economic development, use of natural resources, and so on. So it is also a place within the volume in which some degree of synthesis can be accomplished, in addition to its challenge to compare and contrast regional contexts.

21.2. Defining Regions

The climate system may be global in extent, but its manifestations – through atmospheric processes, ocean circulation, bioclimatic zones, daily weather and longer-term climate trends – are assuredly local in their occurrence, character and impact. Explicit recognition of geographical diversity is therefore an imperative for any scientific assessment of anthropogenic climate change. Regional heterogeneity is also a fundamental consideration in designing appropriate policies for managing the challenges of climate change. The following sections emphasize some of the crucial regional issues to be pursued in Part B of this report.

21.2.1. Regional Manifestations of Climate Change

Climate change respects no political boundaries and can be highly variable from region to region, regardless of whether it is anthropogenic or natural in origin. Similarly, the impacts of climate change, the vulnerability of different socio-economic sectors and the availability of adaptation policies are strongly region-specific. Finally, the formulation of mitigation strategies and the implementation of mitigation technologies are intimately related to local/regional development issues. The most effective treatment of regional aspects of the observed and projected physical climate, its impacts and response options may frequently be at odds with the scales at which political decisions need to be made. This has been the dilemma facing IPCC author teams in successive assessments. Some of their earlier attempts at reconciling this mismatch have been summarized in Box 21-1.

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Box 21-1. Treatment of Regions in Previous IPCC Reports

There has been an evolution in the treatment of regional aspects of climate change in IPCC reports from a patchwork of case examples in the First Assessment Report (FAR) and its supplements, through to attempts at a more systematic coverage of regional issues following a request from governments, beginning with the Special Report on the Regional Impacts of Climate Change in 1998. That report distilled information from the Second Assessment Report (SAR) for ten continental scale regions, and the subsequent Third (TAR) and Fourth (AR4) assessments each contained comparable chapters on impacts, adaptation and vulnerability in the Working Group (WG) II volumes. WG I and III reports also address regional issues in various chapters, and use different methods of mapping, statistical aggregation and spatial averaging to provide regional information. Examples of past attempts to represent regional information are presented in Table 21-1. Some of the main topics demanding a regional treatment are:

- *Climate*, typically represented by sub-continental regions, a scale at which trends in observations tend to be fairly robust, and at which signal:noise ratios for projections from global models may also offer some confidence. While maps are widely used to represent climatic patterns, regional aggregation of this (typically gridded) information is still required to summarise the processes and trends they depict. Indeed, examples of maps produced for an atlas accompanying the WG I report can be found in several regional chapters of this volume. Figure 21-1 illustrates how sub-continental land-based regions being used to summarise observed and projected climate map onto the regions defined by chapters in Part B. Specific examples of summary climate information that can be provided at sub-continental scales directly applicable to political regions are provided in Box 21-3.

- *Other aspects of the climate system*, such as the cryosphere, oceans, sea level, and atmospheric composition, also invite a regional treatment, especially given the importance of regional changes, for example, in sea ice cover for navigation, land movements and local circulations that may counter or reinforce global sea level rise, or air pollution that can be a major regional driver of atmospheric radiative forcing.
- *Climate change impacts* on natural resource sectors, such as agriculture, forestry, ecosystems, water resources and fisheries, which often demand a classification of regional types to distinguish contrasting environmental conditions, and the livelihoods and human interventions that accompany them. Here, it is common to classify regions according to biogeographical characteristics (e.g. biomes, climatic zones, physiographic features like mountains, river basins or deltas, or combinations of these).
- *Emissions* of greenhouse gases and aerosols and their cycling through the Earth system have a crucial regional expression that requires combining socio-economic data on human activities responsible for anthropogenic emissions with biogeochemical monitoring of material and gas fluxes worldwide. Since these activities are known to be responsible for anthropogenic climate change, and the UNFCCC and other national and international policies are being designed to modify human activities, the regional units of most relevance for governments are those that provide comparison between political and economic regional groupings worldwide.
- *Global scenarios* of the major socio-economic, technological and land use drivers that affect anthropogenic emissions as well as influencing societal vulnerability to the impacts of climate change, rely heavily on integrated assessment models (IAMs) of the global energy–environment–socioeconomic system. IAMs require historical statistical information from all regions of the world to establish relationships between key driving variables and the observed behaviour of ecosystems, the climate system, energy systems, economic activity and society at large. Quantitative scenarios derived from such models need to be aggregated into regional units of relevance to stakeholders wishing to interpret and apply such scenarios. SRES was the most comprehensive scenario development exercise conducted to date to serve the climate change community, though the scenarios themselves are provided only for four world regions. New scenarios are under development by the global research community, and these are being designed to have more regional detail than SRES (Moss *et al.*, 2010).
- Finally, *human responses to climate change through mitigation and adaptation* demand both global and regional approaches, as emphasised in the Articles of the UNFCCC and manifest in international financing to support climate policy (e.g. via the Multinational Development Banks – CIF, 2012). However, governments require access to useable knowledge that can be applied at national and local scales. That is a regional challenge beyond the scope of an IPCC report alone, but is something that all authors should have in mind as the ultimate deliverable for which these assessments should provide the appropriate context.

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[INSERT TABLE 21-1 HERE
Table 21-1: Selected examples of regional treatment in previous IPCC Assessment Reports and Special Reports (SR). Major assessments are subdivided by the three Working Group reports, each described by generic titles.]

[INSERT FIGURE 21-1 HERE
Figure 21-1: [PLACEHOLDER] Maps showing the 26 regions (land areas only) used to summarise projected changes in climate in this chapter (upper panel – IPCC, 2012) and the regions defined for Chapters 22-29 in Part B (lower panel – IPCC, 2001). Note that information is also provided in this chapter on projected climate over the open oceans. [Maps to be redrawn and combined when climate regions and AR5 chapter regions clarified]**]**

21.2.2. Regional Dimensions of Climate Change Response

This is the first full IPCC assessment to devote a single part of a report to regional aspects of climate change that cut across topics in all three IPCC Working Groups. Hence, the scope of the report includes all those regional dimensions of the climate change issue that are regarded as relevant to international policy making. Furthermore, as the demand for information to support practical decision-making assumes an increasingly sub-national focus, this can only accentuate the challenge facing the authors of this report. However, though expeditious use of case studies can provide useful illustrations of local-scale phenomena, geographical comprehensiveness is necessarily ruled out in an international assessment of this kind. Instead, responsibility for compiling and disseminating local information rests with regional and national experts, and IPCC reports seek to highlight robust examples of these, wherever possible.

In addition to scale issues, the implications of climate change also touch on almost all sectors of society, so policy makers face a dual challenge in achieving policy integration – vertically, through multiple levels of governance, and horizontally, across different sectors (Figure 21-2). Many of the barriers to effective climate response are to be found in these two dimensions. For instance, in the vertical dimension, while a growing number of European countries have developed national adaptation strategies in recent years, the implementation of adaptation measures at a local level has lagged behind, because responsibility and resources for adaptation at the local level have yet to be properly assigned (Biesbroek et al., 2010). In contrast, horizontal integration (policy coherence – Mickwitz, 2009) often flies in the face of conventional practice, with sectoral policies that are designed to advance social or economic goals (e.g. development of an improved road network) often at odds with goals set in other sectors (e.g. environmental targets to limit greenhouse gas emissions or to reduce infrastructural exposure to flood risk).

[INSERT FIGURE 21-2 HERE
Figure 21-2: Horizontal and vertical climate policy integration (Mickwitz et al. 2009). Vertical policy integration can occur within as well as between levels, and may extend to supra-national and global levels (not shown). [possibly redraw to include international dimensions]]

At the international level, the United Nations Framework Convention on Climate Change (UNFCCC) is explicit in its definitions regarding the status and groupings of its signatories or "Parties" (UNFCCC, 1992). The principle of "common but differentiated responsibilities" refers to a common goal of Parties to achieve the objective of the Convention and to implement its provisions, while recognizing specific national and regional development priorities, objectives and circumstances. The most fundamental distinction is drawn between the Annex I Parties, comprising industrialized (developed) countries[1], and the Non-Annex I Parties, which are mostly developing countries (Table S21-2). Annex I OECD members are further designated as Annex II Parties. These Parties have special responsibilities to provide financial assistance to developing countries as well as promoting the development and transfer of environmentally friendly technologies to transition economy Parties and developing countries. All but two of the Annex I Parties (Belarus and Turkey) also signed up to emissions limitations or reductions under the Kyoto Protocol (Annex B – Table S21-2). Developing countries eligible to receive official development assistance (ODA) are classified by the OECD according to per capita income. 48 of these are designated by the United Nations as Least Developed Countries (LDCs)[2], and are recognized under the Convention as meriting special consideration on account of their limited capacity to respond to climate change and adapt to its adverse effects.

[INSERT TABLE S21-2 APPENDIX – SUPPLEMENTARY MATERIAL
Table S21-2: [Proposed that this be moved supplementary material] Countries and territories of the world, their regional treatment in this report and some other illustrative groupings of relevance for international climate change policy making. Sources (status in May 2012): AOSIS (2012), Arctic Council (2012), European Commission (2012), G77 (2012), OECD (2012), OHRLLS (2012), OPEC (2012), Secretariat of the Antarctic Treaty (2012), UNCLOS (2012), UNFCCC (1992, 1998, 2012). [If supplementary material, possibly to be used in conjunction with an interactive map and other statistical information, e.g. population, GDP, HDI?]]

[FOOTNOTE 1: Members of the Organisation for Economic Co-operation and Development (OECD) in 1992 plus transition economies.]

[FOOTNOTE 2: LDC status is determined by the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (OHRLLS) according to three criteria: gross national per capita income (GNI), a composite human assets index (HAI), based on indicators of nutrition, health, education and literacy, and an economic vulnerability index (EVI) based on seven economic indicators.]

The Convention also contains descriptions of regional types without specifying which countries fall within these categories. For example, Article 4 of the Convention describes the following regional types in relation to funding, insurance and the transfer of technology: (a) small island countries; (b) countries with low-lying coastal areas; (c) countries with arid and semi-arid areas, forested areas and areas liable to forest decay; (d) countries with areas prone to natural disasters; (e) countries with areas liable to drought and desertification; (f) countries with areas of high urban atmospheric pollution; (g) countries with areas with fragile ecosystems, including mountainous ecosystems; (h) countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and (i) landlocked and transit countries. Two of these (Landlocked Developing Countries and Small Island Developing States) are recognized by the United Nations Office of the High Representative for the Least Developed Countries (OHRLLS) (see Table S21-2).

While the UNFCCC and its associated Protocols require global agreement to come into effect, the implementation of policies to meet these agreements occurs at national level. Moreover, the negotiating process is often conducted among regional groupings of nation states. Some examples are shown below (from past COP[3] meetings):

- African Group
- Alliance of Small Island States (AOSIS – Table S21-2)
- Asian Group
- A group of countries of Central Asia, Caucasus, Albania and Moldova (CACAM)
- Environmental Integrity Group (EIG) comprises: Mexico, the Republic of Korea and Switzerland
- European Union (Table S21-2)
- Group of 77 and China[4] (Table S21-2)
- OPEC (Organization of the Petroleum Exporting Countries – Table S21-2)[5]
- Umbrella group: a loose coalition of non-EU developed countries, usually comprising: Australia, Canada, Iceland, Japan, New Zealand, Norway, the Russian Federation, Ukraine and the USA.

[FOOTNOTE 3: The Conference of the Parties (COP) comprises all Parties to the Convention and is its supreme decision-making authority.]

[FOOTNOTE 4: The Group of 77 (G-77) was established on 15 June 1964 by seventy-seven developing country signatories of the "Joint Declaration of the Seventy-Seven Countries" issued at the end of the first session of the United Nations Conference on Trade and Development (UNCTAD). Although the membership of the G-77 has increased to 130 countries, the original name was retained because of its historic significance.]

[FOOTNOTE 5: OPEC is an international organization of 12 developing countries that are heavily reliant on oil revenues as their main source of income. Membership is open to any country which is a substantial net exporter of oil and which shares the ideals of the organization.]

Many of the initiatives emerging out of the UNFCCC process, are focused on capacity building at national-scale (e.g. the Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change – (UNFCCC, 2007)) while the international financial mechanisms for implementation of response measures (e.g. the Clean Development Mechanism for emissions reductions under the Kyoto Protocol (UNFCCC, 1998), or the Green Climate Fund to support adaptation actions under the Convention (Green Climate Fund, 2012)) are administered by committees drawn from different regional groupings.

It is also becoming clear that as climate change impacts become felt in different regions, some existing international institutional alignments are facing new challenges. For instance, the opening of new transport routes in the Arctic (see section 21-6 and Chapter 28) coupled with new opportunities to exploit natural resources in the region and a number of territorial disputes, have raised national security concerns that the existing laws governing access and sovereignty may be too flimsy, and that institutions such as the Arctic Council may need to be strengthened to match the unified legal framework already in place for the Antarctic under the Antarctic Treaty (Bergman Rosamond, 2011; Government Office for Science, 2011). However, although there is no single legally binding Arctic environmental regime, there are already strong provisions within the United Nations Convention on the Law of the

Sea (Stokke, 2007). Signatories of the Antarctic Treaty and UNCLOS, and members of the Arctic Council are indicated in Table S21-1. Similar challenges face international authorities faced with large numbers of migrants, some of whom are moving directly or indirectly as a result of envirinmental change (see Section 21.6.2).

Finally, as an interesting curiosity, but also to illustrate how international agreements can be used to promote regional development, and hence might also be promising instruments for furthering trans-national aspects of climate policy, it can be noted in Table S21-1 how a large number of UNCLOS signatories are actually Landlocked Developing Countries (LLDCs). This is merely recognition that the Convention makesprovision for LLDCs and other "geographically disadvantaged States" to participate in the equitable exploitation of resources in the exclusive economic zones of coastal neighbours, as well as being guaranteed rights of access and tax-free transit via coastal ports (UNCLOS, 1982).

21.3. Assessment of Methods of Regional Adaptation/Vulnerability/Assessment Literature

Assessing climate vulnerability or options for adapting to climate impacts in human and natural systems requires an understanding of all factors influencing the system and how change may be effected within the system or applied to one or more of the external influencing factors. This implies the need, in general, for a wide range of climate and non-climate information and then determining how this may be used to enhance the resilience of the system. Firstly in this section, the context in which systems operate and relevant knowledge can be applied is explored from which a broad description of the information requirements can be deduced. This is followed by assessments of new sources of, and thinking related to baseline and recent trend information necessary for defining impacts baselines and assessing vulnerability and then the future scenario information used for assessing impacts, changes in vulnerability and options for adaptation. The section concludes with an assessment of the credibility of the various types of information presented.

21.3.1. Decision-Making Context

This section deals with understanding the different types of situation in which decisions related to the impacts of climate change are being made, and what human and natural systems are involved. This understanding allows the types of information required to be defined along with the characteristics of the quantities involved, such as the level of spatial or temporal detail or measures of quality.

As discussed in the IPCC SREX (IPCC 2012), the selection of appropriate vulnerability and risk evaluation approaches depends on the decision-making context. Different decision-making contexts lead to different choices of climate variables and of the geographic and time scales on which they need to be provided. They also lead to different ways to best characterize vulnerability, and in how to define and evaluate adaptation options, in the context of uncertainty about not only the future climate, but also many other aspects of the system at risk. In addition, the decision-making context also defines which assessment approach is most appropriate. Some decision-making contexts, such as the design of large infrastructure projects, may require rigorous quantitative information to feed formal evaluations, often including cost-benefit analysis. Others, such as local decision-making in traditional communities, may benefit much more from experienced-based approaches, or story-telling to evaluate future implications of possible decisions. In most cases, an understanding of the context in which the risk plays out, and the “menu of options” that may be considered the manage it, are not an afterthought, but a defining feature of an appropriate climate risk analysis, which requires a much closer interplay between decision-makers and providers of climate risk information than is often occurring.

While the importance of considering the decision-making context is a general issue for all vulnerability, impacts and adaptation assessments, it is of special importance in the context of regional and sub regional assessments. Many studies are still driven by global data and methods, whereas there is considerable variation in regional, national and local decision-making contexts, as well as across different groups of stakeholders and sectors. There is a growing body of scientific information on how to provide the most relevant climate risk information to suit specific decision-making processes [add refs].

21.3.1.1. Policy or Decision-Making Context

The most defining characteristic of the decision-making context is *by whom* decision are being taken. This may range from international policy processes, to national government departments, to individual farmers.

Historically, except for studies purely from a research perspective, many climate change risk assessments have been undertaken either in the context of the UNFCCC, or by (or for) *national governments*. The purpose was often to define the long-term international or national implications of climate change, to assess the priority that would need to be given to climate change mitigation, or to assess long-term risks to specific countries, regions, and sectors. Clearly, the level of current development, which often strongly relates to the size of the current “adaptation gap”, is an important determinant in that level of vulnerability. Such differences in levels of development, as well as specific regional geographic characteristics, continue to be an important component of regional differences in the climate change adaptation policy-context.

As attention has shifted towards implementing adaptation, more and more attention is also being paid to more sector-specific risk assessments intended to guide development planning and specific investments, by governments, but also other actors in societies (e,g, add ref to UKCIP), including at the most local levels.

International organizations including the UN and its specialized agencies, as well as the World Bank and regional development banks, have inreasingly sought to integrate climate risk management in their regular programs, and in their support to (particularly developing country) governments. Many climate information sources initially started globally but have increasingly been tailored to specific country circumstances (e.g. World Bank climate-adaptation country profiles that aim to provide a more comprehensive assessement of country risk, UNDP country profiles, focusing only on climate information). Documents such as the UN-DAF and the World Bank’s Country Assistance Strategy increasingly aim to mainstream climate adaptation into their development assistance to individual countries. Specifically climate-oriented investments, such as specific projects funded by international climate financing mechanisms, also build on specific analyses of climate information, often carried out by the recipient government with assistance from the international organization involved.

At regional and subregional scale, the climate adaptation decision-making context also includes a range of *regional intergovernmental organizations*, from continental ones such as such as OAS, and the African Union, to sub continental ones such as ECOWAS, IGAD and SADC within sub-Saharan Africa. Most of these organizations are active on topics and in sectors that are significantly affected by climate risk, and many have developed climate change related policies or plans [add examples?].

Civil society organizations, ranging from international NGOs to local community-based organizations (CBOs), with big differences in level of awareness and technical capacity to take climate risk into account into their activities (and to integrate technical climate information into their adaptation work, to the extent relevant). Some, such as the Red Cross and Red Crescent Movement and CARE international, have established dedicated units to build capacity for climate risk management and related work, and to provide guidance on climate risk assessment and appropriate use of climate information.

Another important category of users is the *private sector*, ranging from large multinationals to small local enterprises and individual farmers. In most sectors, private sector use of climate information is often focused more on the current and near-term climate (including what has already changed), except in the case of requirements to include climate risk assessments in Environmental Impact Assessments, or in the case of large investments directly affected by long-term trends in climate (with a long investment horizon and substantial exposure and vulnerability to changing climate conditions).

Individuals are also affected by climate individually, by impacts on their livelihoods, well-being and health, including through the direct impact of extreme events.

Decision-making by individual, communities, and private companies significantly affects the adaptive capacity of societies at large. To some extent, their decision-making is affected by the context of government policies and legislation. However there are substantial regional and subregional differences in the way these individuals, communities and the private sectors relate to the government, both in terms of the extent to which the government's policies affect private behavior, and the extent to which government information is trusted and acted upon and thus results in behavioral change. In addition, there are significant regional and subregional differences in the extent to which individuals, especially the most vulnerable, can influence government decision-making, which in itself is an aspect of adaptive capacity.

21.3.1.2. Consideration of Adaptation Approaches, Options, Possible Decisions, Adaptive Capacity, Constraints

Another defining question is the approach to adaptation. If plans or projects are designed specifically to adapt to a changing climate, climate risk information has quite a central role in the decision-making. Examples include National Communications to the UNFCCC, NAPAs, SPCRs, but also climate change strategies developed by local towns, by international organizations, etc.

More frequently however, climate change is being considered as a smaller component of a regular set of considerations for a particular decision. Examples include government sector plans, a particular infrastructure investment, or even the day-to-day decisions by a local farmer. In such a context, the question is not just what is the best available climate information, but also whether that information is relevant given the nature of the decision being taken, and the constraints faced by the actors involved. When framed as a risk management problem, the question is also not just about the nature of the risk and the uncertainties about possible future conditions, but also about relative costs and benefits of the "menu of options" available to manage that risk.

In many cases, climate change may merely provide an incentive for choosing a more robust strategy, which leaves more flexibility for future risk management. In such contexts, the focus may shift from approaches to formally factor in climate information in specific technical design decisions, to one where the emphasis is on building adaptive capacity, and the analysis should primarily focus on capacities and constraints rather than technical climate analysis.

A particularly important aspect in cases where climate is only one of many factors (and thus risks being ignored) is to avoid maladaptation, which may result from decisions taken unaware of potential changes in climate risk. As highlighted in SREX (IPCC 2012), some decisions taken to manage short-term climate risk may result in maladaptation in the longer term.

21.3.1.3. Time Scales of Interest

As stated in SREX (IPCC 2012), observed and projected trends in exposure, vulnerability, and climate can inform risk management and adaptation strategies, policies, and measures, but the importance of these trends for decision making depends on their magnitude and degree of certainty at the temporal and spatial scale of the risk being managed, as well as on the available capacity to implement risk management options.

Many climate change impacts assessments have traditionally focused on the longer-range future (2050-2100), whereas many decisions taken today have a planning horizon of a few months, years, maybe up to 2 decades. For many such shorter-term decisions, adaptation to recent climate variability and observed trends may be sufficient (Hallegatte 2009). In doing so, there is often scope to make better use of climate information on shorter timescales, including better use of current climatologies and seasonal climate forecasts (HLT, 2011). For longer-term decisions, questions about maladaptation, and sequencing of adaptation options become much more pertinent.

21.3.1.4. Spatial Scales of Interest

A lot of climate change adaptation planning is still taking place at the national scale, partly due to the challenges involved with the proper communication of relevant climate information at the local level (given both the uncertainties involved and the mode of communication). However, as also noted in SREX (IPCC, 2012) better use of local level risk and context analysis methodologies, increasingly accepted by many civil society and government agencies working on adaptation at local level, could enhance climate risk management at multiple levels.

Decisionmaking for large-scale structural measures is often based on cost-benefit analyses and technical approaches. Household-level (and many other local) climate-affected decisions, particularly those involving changing regular practice or behavior, are often made much more intuitively, with a much greater role for a wide range of social and cultural aspects. This poses very different demands on the type of climate information provided (see SREX Box 5-2).

Multi- criteria analysis, scenario planning, and flexible decision paths offer options for taking action when faced with large uncertainties or incomplete information, and can help bridge adaptation strategies across scales (in particular between the national and local level) (SREX ch 5/6).

_____ START BOX 21-2 HERE _____

Box 21-2. SREX-Derived Information on Communication of Local Risk-Based Information

[Placeholder – to be developed subject to materials from FOD in other WGII chapters]

_____ END BOX 21-2 HERE _____

21.3.1.5. Sectors of Particular Interest

Sectors of particular interest clearly include those most affected by climate risk, such as environment/forestry, agriculture/food security, coastal zone management/fisheries, water resources, infrastructure/transportation/energy, health, as well as finance and tourism. Decisions in each of these sectors occur at a range of time scales and spatial scales. Some, such as infrastructure, are primarily national. Others, such as water resources management, sometimes have some transboundary aspects. Agriculture has strong market interactions with other countries and regions, and tourism and finance are even more international in character. In addition, there are strong couplings between different sectors, for instance, when hydropower dams supply electricity as well as irrigation for agriculture, as well as drinking water for urban areas. Development decisions affect risks in the near-term and longer-term, and need to be managed taking into account the trade-offs between these different sectors and users. Climate information, in this case with a strong emphasis on variability and extremes, but also the longer-term implications of potential trends, needs to be presented so it can help better manage to the existing technical and political trade-offs. Hence, many of the assessments required are in the end local in nature, and will very strongly from region to region, country to country and even place to place.

21.3.2. Baseline Information and Context – Current State and Recent Trends

This section deals with defining baseline information relevant to the assessment of climate change vulnerability, climate change impacts and adaptation to climate change. Baseline here means the reference state or behaviour of a system, e.g. the current biodiversity of an ecosystem, or the reference state of factors (such as climate elements or agricultural activity) which influence that system. In the pure climate context, the phrases pre-industrial or historical baselines are used to define the (reference state of the) climate prior to changes in the atmospheric composition (from its baseline pre-industrial state). In an adaptation context, a baseline could be the impacts on a system under a given amount of climate change prior to changes in non-climate factors (e.g. improved early warning systems, modifying infrastructure) aimed at reducing the impacts. This section does not consider methods for calculating baselines involved in assessing vulnerability of, impacts in and adaptations to systems – but methods for deriving the information on climatic and non-climatic factors used to calculate these baselines.

There are several important properties of baselines to consider when assessing methods to derive relevant information. Defining a reference state sufficiently well that it provides for a good measure of a system's vulnerability or for testing whether significant changes have taken place implies that much of the variability of the system needs to be captured. Thus the information used to establish this reference state must account for the variability of the factors influencing the system; in the case of climate factors at least 30 years and often substantially more is required (e.g. Kendon et al., 2008). Also the temporal and spatial properties of the system under investigation will influence the information required to establish a reliable baseline. Many systems operate at or depend on high resolution information, for example the high spatial resolution of urban drainage systems or organisms within ecosystem sensitive to temperature extremes thus requiring information at the daily time-scale.

Clearly, in defining baselines for assessing climate change impacts, vulnerability or adaptation, a wide range of information will be required as the systems being studies generally comprise interacting physical and human components influenced by climatic and non-climatic factors. For example the assessment of options to respond to river flooding will require information on some or all of the following: past and future rainfall/river flow sequencing and river channel modifications; likelihood of riverside development; viability of property insurance; regional or national finances; effectiveness of relevant institutions. In this case information is required on climate and other physical aspects of the system as well as social and economic factors and this will generally be so. The rest of this section then assesses methods to derive climatic and then non-climatic information relevant to establishing these baselines.

21.3.2.1. Climate Baselines

Fundamental to the study of climate change impacts is to establish an "impact baseline", the behaviour of the system under a reference climate. The baseline information defining this reference climate may be derived from either or a combination of observations or models, with the spatial and temporal resolution generally prescribed by the source, and the choices generally depending on the application. For example Challinor et al. (2004) use observed weather inputs at the daily timescale and coarse spatial resolution with a crop model to demonstrate its ability to simulate a realistic range of yields under historical climate variability to motivate using the model to estimate quantitatively the effect on yields of perturbed climates (e.g. Challinor et al., 2006). Arnell et al. (2003) used a range of climate baselines to study the effect of different choices on the characteristics and ranges the impacts (and paid less attention to the validation of the impacts baselines). In a further example Bell et al., (2009) use high quality observed data at daily timescale and 5km resolution to demonstrate the ability of a river flow model to simulate an accurate baseline over a 1km river network in order to establish confidence in the impacts model. This is then used with less accurate climate model-derived baselines that are then compared with results when using climate-model derived futures (Bell et al., 2011). In this case the impacts model is being used with plausible time-series of climate variables to derive realistic (though not necessarily accurate) high resolution baseline and future river flows and thus ranges of climate change impacts which can be considered realistic responses to the imposed climate perturbations. In a more comprehensive study of impacts of climate change in selected UK rivers, Kay and Jones (2011) used different baselines from the UKCP09 scenarios (Murphy et al., 2009) and noted that the changes were similar when using either weather generator or RCM baseline information. However, a greater range of projected changes resulted when using high time-resolution (daily rather than monthly) information (Figure 21-3), underscoring the importance of including the full spectrum of climate variability when assessing climate impacts.

[INSERT FIGURE 21-3 HERE
Figure 21-3: The range of percentage change in flood peaks for nine UK catchments at the a) 2-year and b) 20-year return period. Box-and-whisker plots are used to summarise results when using 10,000 UKCP09 Sampled Data (Murphy et al. 2009) change factors (red) and 100 sets of UKCP09 current and future Weather Generator time-series (cyan). Also plotted, are the results when using 11 sets of RCM-derived change factors (red crosses) and when using 11 sets of RCM current and future times-series (green rectangles). The box delineates the 25^{th}-75^{th} percentile range and the whiskers the 10^{th}-90^{th} percentile range, with the median (50^{th} percentile) shown by the line dividing the box.

Additional markers outside the whiskers indicate the minima and maxima, if within the plotted range of -50 to +100. The points derived from the RCM results are joined for the corresponding members of the RCM ensemble (grey lines), and the medians for these methods are shown by black horizontal bars.]

These examples show that a good description of the baseline climate, i.e. in general including information on its variability on timescales of days to decades, is important for developing the reference state or behaviour of a climate-sensitive system for determining impacts on or the vulnerability of the system. This has motivated significant efforts to enhance both the quality and length of observed climate records and to make these data more easily available. This has included derivation of new observational dataset such as APHRODITE (a gridded rain-gauge based dataset for Asia, Yatagai, et al., 2012), coordinated analysis of regional climate indices and extremes by CLIVAR's ETCCDI (http://www.clivar.org/organization/etccdi, see e.g. Zhang et al., 2011) and data rescue work typified by the ACRE initiative (Allen et al., 2011) and the associated 20th Century Reanalysis (20CR) project (Compo et al., 2011). These have resulted in analysis and digitization of many daily or sub-daily weather records from all over the world with digitized surface pressure data then being used in 20CR to reconstruct the global evolution of the weather from 1871 to present day (Figure 21-4). 20CR provides the basis for, at any location, estimating historical climate variability from the sub-daily to the multi-decadal timescale and hence developing robust estimates of the baseline sensitivity of a system to the climate (and addressing related issues such as establishing links between long-term climate trends and observed impacts). Other reanalyses (http://reanalyses.org/) have also been constructed in recent years, mainly focusing on developing higher quality reconstructions for the more recent period. They include a new European Centre for Medium Range Weather Forecasting (ECMWF) Reanalyses (ERA) dataset, ERA-Interim (Dee et al., 2011) for the period 1979-2010 which is both higher resolution and more homogeneous than previous ERA datasets (ERA40 and ERA15), the NASA Modern Era Reanalysis for Research and Applications (MERRA), 1979-present (Rienecker et al., 2011), the NCEP Climate Forecast System Reanalysis (CFSR), 1979-Jan 2010 (Saha et al., 2010) and regional reanalyses such as the North American Regional Reanalysis (NARR) (Mesinger et al., 2006) and EURO4M (Klein-Tank, 2011).

[INSERT FIGURE 21-4 HERE
Figure 21-4: Time series of seasonally averaged climate indices representing (a) the tropical September to January Pacific Walker Circulation (PWC), (b) the December to March North Atlantic Oscillation (NAO), and (c) the December to March Pacific North America (PNA) pattern. Indices are calculated from various sources: 20CRv2 (pink); statistical reconstructions using Bronnimann *et al.* (2009) for the PWC, Griesser *et al.* (2010) for the PNA, and HadSLP2 (Allan and Ansell, 2006) for the NAO (all cyan); NCEP–NCAR reanalyses (NNR; dark blue); ERA-40 (green); ERA-Interim (orange); and SOCOL ensemble mean (dark grey). The light grey shading indicates the minimum and maximum range of the SOCOL ensemble. All indices are computed with respect to the overlapping 1989–1999 period. Indices are defined as in Brönnimann *etal.* (2009).]

As noted in the introduction, the scale of the system being investigated often implies the need for high resolution climate information, either observed or simulated, to calculate its baseline or reference behaviour. Observed high-resolution climate baselines are not available in many regions or for all variables required (e.g. Washington et al. 2006, WMO 2003). The recent reanalyses provide globally complete and temporally detailed reconstructions of the climate of the recent past but generally lack the resolution which would enable them to represent the fine spatial details of weather events often important when modeling the response of systems sensitive to climate. In this case higher resolution downscaling, using dynamical or statistical models to add fine-scale detail (see e.g. Maraun et al., 2010), can be used in conjunction with the reanalyses (e.g. Duryan et al., 2010 for West Africa). This idea is being explored in the WCRP-sponsored Coordinated Regional Downscaling Experiment (CORDEX) project (http://wcrp.ipsl.jussieu.fr/SF_RCD_CORDEX.html and see Giorgi et al., 2009) in which the initial experiment is to downscale ERA-Interim over all land and enclosed sea areas.

Downscaling is also applied to outputs from global climate models (GCMs) to produce purely model-based high resolution climate baselines. These, along with downscaled climate projections from the same GCMs, can be used directly to assess the impacts of the projected high-resolution climate changes. Historically, the more usual approach has been to use observed baselines and then add climate changes derived from climate projections to these and then calculate the impact using this perturbation of the observed baselines. This was the only viable approach to take when high resolution input data were required to assess impacts or vulnerability and only coarse resolution GCM-based projections were available. Now high-resolution projections are becoming increasingly available both direct and perturbed baseline approaches can be used. The direct approach has the disadvantage that the baseline climate will often contain significant errors and their influence on the calculated impact will need to be addressed. The perturbed baseline approach has the disadvantage that in order to calculate a plausible future climate accounting for the full detail of projected climate change the perturbations applied should account for changes in those aspects of climate variability that the system being studied is sensitive to.

21.3.2.2. Non-Climatic Baselines

As described in the introduction to 21.3.2, defining baselines for assessing climate change impacts, vulnerability or adaptation will, in general, require information on non-climatic factors influencing the system being studied. These can include aspects of the physical environment, such as atmospheric composition (e.g. affecting air quality or CO_2 availability for plant growth) and land-cover/use (e.g. defining the urban environment or availability of agricultural land), and of the socio-economic context in which the system operates. The latter category includes factors such as demography, level of socio-economic and educational development, political/governance and technology. Thus as with the climatic baselines discussed above, information is required on the baseline state of these factors to enable reference behaviour of system to be calculated for assessing its vulnerability or the effects of changes in these factors in enabling the system to adapt. To provide a comprehensive assessment of how or whether a system can adapt to climate change it is necessary to assess its vulnerability in respect of all non-climatic factors that may influence it. Given the diversity of non-climatic influences on many climate-sensitive systems baseline information on a wide range of factors will often be required. For example agriculture, water resources, ecosystems and health are all affected by a diverse range of (non-climatic) physical factors and socio-economic influences, e.g. availability of irrigation systems for agriculture or the effectiveness of disease prevention.

As with climate baselines, there is much information on many of these factors and in many cases there is already significant work that has been done in collecting and making this available. In the case of the physical factors, information on many of these have been refined and updated as they are critical inputs to deriving the climate forcings in the Representation Concentration Pathways (RCPs, van Vuuren et al., 2011) used in the CMIP5 (Taylor et al., 2009) experiments. For example these included updated information on land-use change (Hurtt et al., 2010), atmospheric composition (Meinshausen et al., 2010) and aerosols (Grainer et al., 2011, Lamarque et al., 2011). Other aspects of the physical environment in many areas have been well-studied and detailed records are available (e.g. through improved satellite observations and observational processing or via research by international bodies e.g. FAO assessing agriculture and forestry systems). However, much like with climate observations, there are still areas of the world which are less well-observed where rescuing and/or making available old records of the physical environment is of significant value as is making new or more detailed observations.

For the socio-economic factors, local and national governments and international agencies (e.g. UN agencies, World Bank - http://data.worldbank.org/data-catalog) have been collecting data on the human-related factors for many decades and similarly information on technological developments is widely available. In these cases, generally a baseline as a reference state of a given factor is not able to be defined as they are generally continually evolving. In this instance a baseline will be a particular reference point in the evolution of the factor in question, for example the population of a city or the annual income of agricultural workers in a particular region over a given five-year period. In these cases it is important to be aware that baseline information of this nature has a shorter period of validity than much of the physical (climate and non-climate) baseline information.

The importance of the non-climatic baseline information being assessed here is how it defines the baseline vulnerability of the system and so how changes in these factors can allow it to adapt to climate change, i.e. compensate for increased climate vulnerability. Generally climate has been viewed as a factor which varies a known amount around a base state and thus the idea of defining which non-climatic information is relevant to assessing how a system in vulnerable and can adapt to climate change is relatively new. This implies that a key step in assessing adaptation to climate change in a system is defining information on the non-climatic factors which influence its vulnerability. Given the diversity of climate-sensitive systems as explained above, it is not possible to assess methods for deriving all non-climatic baselines relevant to vulnerability and adaptation studies. In some cases, this information will be able to be derived from available data sources and in other cases it will be deficient (e.g. in resolution) or missing. As a result, the rest of this section will concentrate on presenting several studies which demonstrate these various cases as a guide to how relevant non-climatic baselines can be derived and interpreted.

The issue of establishing an appropriate non-climatic baseline, in this case in the physical environment, is illustrated with a simple example in a study of climate change impacts on flow in the River Thames in the UK. Despite increases in temperature and a major change in the seasonal partitioning of rainfall over the Thames basin there is no long-term trend in annual maximum flows over a 126 year series (Marsh 2004). In the 19th century summer rainfall was on average greater than in winter, a situation reversed by the end of the 20th century due to respectively negative and positive precipitation trends which would be expected to have influenced maximum flows. An investigation of the physical environment found that it had been significantly modified as part of river management activities with increases in channel capacity of 30% over 70 years leading to fewer floods in the lower Thames. Thus in this case, establishing the current level of vulnerability of the Thames to flooding required a detailed investigation to determine the appropriate baseline for the physical factor (river channel capacity) influencing this vulnerability.

A second simple example involves a study of the potential for adaptation in response to projected climate change impacts on crop yields (Challinor et al., 2009). The relevant non-climatic factor in this case was the availability of alternative crop varieties. In this case detailed field studies demonstrated that the current germplasm included varieties with a wide range of tolerance to higher temperatures (Badigannavar et al., 2002). This established an agricultural technology baselines which demonstrated the potential to reduce vulnerability in the system to compensate for the projected climate change impact.

21.3.3. Characterizing the Future

21.3.3.1. Development of Scenarios and Projections

Since the AR4 there have been mainly three new developments in the realm of scenarios and projections: 1) the development and application of higher resolution climate scenarios from regional climate model simulations; 2) further use of multiple scenario elements as opposed to use of climate change scenarios only; and 3) a new approach to the construction of global scenarios for use in climate change analysis, initiated with the development of representative concentration pathways (RCPs).

21.3.3.1.1. High-resolution scenarios

There have been large numbers of new simulations with regional climate models (see section 21.4.1.1), e.g., over Europe (ENSEMBLES), over North America (NARCCAP), over Asia (RMIP), over South America (CLARIS and Marengo et al. 2011), over India (HIGHNOON), and these are now being used in impacts and adaptation studies (e.g., Miles et al., 2010, Morse et al., 2009). The CORDEX program (Giorgi et al. 2009) is providing an international coordination of high resolution dynamical downscaling of the CMIP5 global models for all regions of the world. The continent of Africa has been the point of departure for the program.

But there has also been applications of simple downscaling techniques (e.g., the delta method, Mearns et al., 2001; and the Bias Correction Spatial Disaggregation method, BCSD, Maurer et al., 2002, 2007). The desire for higher resolution information is largely assumed to result from the needs for impacts and adaptation, but of course, particularly with regard to dynamical downscaling, the purpose is often to produce superior simulations that take into account higher resolution forcings, such as complex topography (e.g., Salathé et al., 2010) or more details in land-atmosphere feedbacks such as in West Africa (Taylor et al. 2011). Applications of some of these new higher resolution results are discussed in section 21.3.3.3. It must be noted that the different means of attaining high resolution climate information for use in impacts and adaptation studies have been noted for a long time (e.g., Giorgi and Mearns, 1991; Giorgi et al, 2001) but there remains many uncertainties on the relative merits of these different techniques, and particularly a paucity of information on when to use what method.

21.3.3.1.2. Use of multiple scenario elements

Many more impacts and adaptation studies now use multiple scenario elements, as opposed to climate change scenarios alone. Some of the most common types of study that uses multiple scenario elements are those concerned with world hunger, where population change, land use, and economic conditions in various parts of the world make up important elements in addition to climate change (e.g., Parry et al., 2004). Arnell (2004) also used multiple aspects of the SRES scenarios in a study of global water resources, another context where population changes and future economic conditions would be critical to the study. Another type of study that commonly makes use of multiple aspects of scenarios are urban heat island and climate change studies concerned with human health (e.g., Knowlton et al., 2008; Rosenzweig et al., 2009). Recently, McCarthy et al. (2010) considered population increase up to 2050, as well as expanded urban areas to determine effects of climate change on urban heat islands. In the European Impacts Program PRESETA multiple aspects of the SRES scenarios (e.g., population and socio-economic conditions) were considered for some of the impacts areas such as human health (Watkiss and Hunt, 2012). The use of multiple scenario elements is associated with the issue of multiple stressors, which is discussed below.

One of the issues that remain somewhat unresolved is that of downscaling scenario elements. The SRES scenarios have been downscaled for Europe, for example (van Vuuren and O'Neil, 2006), but such downscaling has not been accomplished for all areas. The economic activity information in the RCP's (see next section) has also been downscaled to global 0.5 degree grids in some cases, but not all. This information, however, has not yet been examined carefully in the impacts and vulnerability literature. Moreover, vulnerability studies often consider other scenario elements on very local scales, and tend to use other, local sources for these scenario elements, which may or may not be consistent with the larger scale scenario elements.

21.3.3.1.3. New approach to scenario development

For both the TAR and AR4, the main socio-economic and emissions scenarios used were derived from SRES (Nakicenovic et al., 2000). More recently a new approach to developing climate and socio-economic scenarios was adopted. This new approach changed the familiar linear structure, wherein socio-economic scenarios were constructed, these were used to calculate emissions through application of Integrated Assessment Models (IAMs), and from the concentration of greenhouse gasses and aerosols, climate models would simulate the climate response to the forcings. In the new approach, concentrations of greenhouse gases were developed first (Representative Concentration Pathways, Moss et al., 2010), which allowed the climate modeling work to proceed much earlier in the process. Different possible socio-economic pathways were to be determined later, and it was recognized that more than one socio-economic pathway could lead to the same concentrations of greenhouse gases and aerosols. The process of determining the socio-economic scenarios is ongoing (US NAS, 2010). Four different RCPs were developed, corresponding to 4 different levels of forcing (by 2100) based on watts/m2: RCP 8.5, 6.0, 4.5, and 2.6. These embrace the range of scenarios found in the literature, and they also include explicit stabilization strategies, which were missing from the SRES set. In addition, a set of Shared Socio-economic Pathways (SSPs) is being developed that would characterize a wide range of possible development pathways. More information on these scenarios may be found in Chapter 19 (Box 19-3) of WG2, the WG3 Report, and WG1, Chapter 12, section 12.3.1.3. However, due to the time lags that still exist between the generation of the climate change scenarios, and completion of the development of the related socio-economic scenarios, few of the impacts/adaptation studies assessed in WG2 actively use these scenarios. Most of the assessed literature is still based on the SRES climate and socio-economic scenarios.

21.3.3.2. Multiple Stressors

The recognition of the importance of viewing climate change in the context of multiple stressors has increased over time. In AR4 this topic was, naturally discussed in terms of sustainability (Chapter 20) and adaptation (Chapter 17). In the AR5 the issue of multiple stressors is incorporated into most regional and sectoral chapters, and those related to adaptation. Multiple stressors can have independent, synergistic, or antagonistic effects on particular impact areas. Typical stressors, aside from climate change, include changes in population, migration, land use, economic factors (particularly affecting adaptive capacity), technological development, social capital, air pollution, and governance structures, among others. Magrin, Marengo et al. (2011) clearly identify land-use change and shifts in major socio-economic conditions as stressors of equal importance to climate change in considering future conditions in Latin America. In the new chapter on ocean systems Portner, Karl et al. (2011) indicate the central importance of numerous changes in addition to climate (e.g., changes in nutrients), that are strongly affecting ocean ecosystem health. Hijioka, Lin et al. (2011) identify rapid urbanization, industrialization and economic development as major multiple stressors that will likely be compounded by climate change in Asia. The importance of simultaneous changes of frequency in excessive heat events and increases in air pollution have been well documented in the context of human health (Jackson et al., 2010). Human health studies in general tend to require a multiple stressor approach (Morello-Frosch, et al., 2011).

Many of the multiple stressor studies are regional or local in scope. For example Ziervogel and Taylor (2008) examined multiple stressors in South Africa, taking a survey approach. They examined two different villages in Sekhukune and found that a suite of stressors are present in the two villages, such as high unemployment, health status (e.g., increased concern about AIDs), and access to education. Concerns about climate change were only present in the context of other impacts such availability of water. In a study on the Great Lakes region, additional stressors included land use change, population increase, and point source pollution (Danz et al., 2007). They proposed an integrated measure of multiple stresses for the region. Mawdesly et al. (2009) in considering wildlife management and biodiversity conservation note that reducing pressure from stressors other than climate change can maximize flexibility for adaptation to climate change. Stressors in this area are many, including invasion of non-native species, land-use change, and human population increases and shifts. Baker et al. (2008) note the importance of multiple stressors in the case of coral bleaching; these include sedimentation, turbidity, and nutrient loading in addition to shifts in climate. Nelson and Palmer (2007) discuss the effect of the stressors of increased watershed imperviousness, reduction in riparian vegetation, and increased siltation on water temperatures of streams, which in turn affects their suitability as a habitat. Shifts to warm-water species will result. Eakin and Wehber (2009) consider the effects of changes in demographic factors such as age structure and education level in two agricultural case studies in Latin America.

This increased focus on multiple stressors obviously increases the need for a much wider range of data and wider range of projections for the wide range of stressors, across multiple spatial scales.

21.3.3.3. Application of Projections and Scenarios

We provide several examples below of applications of projections and scenarios to impacts and adaptation planning. As impacts and adaptation studies have progressed, more application of projections and scenarios to actual adaptation planning has occurred. A good example of this is the New York City Adaptation Plan (NPCC, 2010), certainly one of the most complete and well-developed adaptation plans in the United States. Scenarios of climate change based on global climate model results (from the CMIP3 database) were downscaled using simple downscaling techniques (Horton et al., 2010). A multi-sectoral analysis of climate risks was conducted (the program adopted a risk assessment approach) that included consideration of effects of future climate on urban infrastructure, energy, water resources, necessary adaptations for sea level rise, and insurance, among others. However, the focus was on climate change, and other possible scenario elements (e.g., population change) were not used.

There are now a number of studies that have used dynamically downscaled information of impacts and adaptation planning. A rather complete analysis of climate impacts including possible adaptations in the Pacific North West of North America was recently conducted (Miles et al., 2010) that used both simple downscaling of the global climate model simulations from CMIP3 (Mote and Salathé, 2010) but also two different dynamically downscaled scenarios (Salathé et al., 2010). The dynamically downscaled scenarios were particularly useful for the assessment of effects of climate change on storm water infrastructure (Rosenberg et al., 2010). Other aspects of the future aside from climate change were used in some of the sectoral analyses, such as population increase to 2025 for effects of climate on energy resources (Hamlet et al., 2010) and climate change along with air pollution scenarios for effects on human health (Jackson et al., 2010 The European PESETA program (Christensen et al. 2012) employed several RCM climate change simulations from the PRUDENCE program to investigate the impacts of climate change over Europe for agriculture, river flooding, human health, and tourism.

The ENSEMBLES project (Christensen et al., 2010) and its suite of high resolution climate projections have spawned a number of impacts studies, such as the effect of climate change on potential energy demand for heating and cooling in the Mediterranean, forest fire risk in Fennoscandia, property damage due to wind storms, crop yields and water resources in Poland, and risk of wheat yield shortfall in the Mediterranean region (Morse et al., 2009) . Means of assessing risks of impacts using probabilistic information formed part of many of these projects.

The ENSEMBLES project and AMMA project (Polcher et al., 2011) developed a strong collaboration in order to provide new regional climate scenarios for use in impacts studies for West Africa. Moreover, large inter-comparison initiatives favoured the evaluation of model components relevant for impact studies, such as land-surface and chemistry models (Ruti et al., 2011).

The United Kingdom Climate Program (UKCP09) has used a combination of parameter permutation experiments (PPEs) based on the HadCM3 global climate model and multi-model ensembles (MMEs), as well as regional climate model results to develop probabilities of changes in temperature and precipitation at a 25 km resolution (Murphy et al., 2009) for all of the UK. This information is being used to determine probabilities of different impacts of climate change and possible adaptations. Results of individual regional climate model simulations are also available. A number of case studies using the UKCP09 scenarios have been developed. For example, Bell et al., (2011) are using the results from 11 RCM simulations to determine potential changes in river flows throughout the UK for the A1B emissions scenario.

Another trend in scenario application is the use of a greater number of climate scenarios either from global or regional models. For example, in the area of impacts of climate change on water resources a number of studies have used more global models (Gosling et al. , 2010; Bae et al. , 2011; Arnell, 2011) or ensembles of regional climate models (Olsson et al. , 2011), and thus present estimates of impact for between 10-25 different climates for a given emissions scenario. In addition, some studies have developed probability distributions of future impacts by combining results from multiple climate projections and, sometimes, different emissions scenarios, making different assumptions about the relative weight to give to each scenario (Brekke et al. , 2009).

Nobrega et al. (2011) apply a number of pattern-scaled GCMs to study the impacts of climate change on water resources in the Rio Grande Basin in Brazil. They used 6 different GCMs and 4 different SRES emissions scenarios and applied them to a large-scale hydrologic model, and found that choice of GCM was the major source of uncertainty in terms of river discharge. Through the CLARIS project (Menendez et al., 2010) multi-regional model climate change scenarios over South America will soon be used for a wide range of climate change impacts studies (e.g., Dengue fever, Degallier et al., 2010).

21.3.4. Information Credibility and Uncertainty

21.3.4.1. Baseline Data

21.3.4.1.1. Climate baselines

Since AR4 there has been significant effort in improving the quality and homogeneity of climate observations due to their importance for monitoring, detecting and attributing observed climate change (AR5-WG1 Chapter 2). For some variables error estimates have been developed for observed climate records (e.g. Morice et al., 2012 for the HadCRUT near-surface temperature record) and for others such as precipitation, increased focus on improving existing datasets (e.g. Rudolf et al., 2011) and developing new ones (e.g. TRMM (Huffman et al., 2007) or APHRODITE, Yatagi et al.; 2012) enables observational uncertainty to be estimated. This allows us to more accurately quantify the amplitude of natural variability important for detecting trends or establishing impacts or vulnerability baselines.

Another area of significant progress has been in the development of improved and new global reanalyses (21.3.2). Variables from the first generation of reanalyses often contained discontinuities in time (often resulting from changes in the observations they used) thus clearly were not suitable for defining trends (Thorne and Vose, 2010) and needed to be used with caution to define climate baselines. In addition, reanalyses combine observations, generally with global coverage, with models and thus those outputs less directly constrained by the observations are subject to model error. For example, precipitation derived from the ECMWF's ERA15 and ERA-40 reanalyses did contain significant biases which have been much reduced in the more recent ERA-Interim dataset (Dee et al., 2011). As with recent efforts on observational datasets, the production of several reanalyses from different international centres (AR5-WG1 Box 2.3) means that the uncertainty in their of climate baselines can be estimated. In the case of 20CR (Compo et al., 2011) a 56 member ensemble of reconstructions was calculated. This is useful in assessing the credibility of the reanalysis in the regions in the early part of the 140-year reconstruction where there were sparse (or no) observations and also to give an estimate of the inherent uncertainty in detail provided by these reanalyses even where there are good observations.

In many regions for many or all of these data sources there are issues with the credibility of the data from the perspective of their resolution. Some climatological datasets only provide monthly mean data and thus lack temporal variability and often lack sufficient spatial resolution, especially in the context of defining climate baselines to calculate vulnerability and impacts baselines in many systems. In these cases, reanalyses can be combined with either statistical or dynamical downscaling to provide higher resolution simulations of the variables required consistent with the (usually accurate estimate of the) large-scale drivers from the reanalyis. Available observations can then be used to estimate the error in the downscaled simulation. An example of this methodology and the resulting biases can be seen in Figure 21-5 showing results from nine regional climate models driven by ERA-Interim for the period 1990-2007 for a region encompassing West and much of Central Africa. Many models show significant biases and thus may not be considered sufficiently accurate to provide the required additional detail on the climate baselines for the region.

[INSERT FIGURE 21-5 HERE
Figure 21-5: Observed 1990-2007 annual precipitation climatology from GPCC (Rudolf et al., 2011), top left, and, in the remaining panels, related systematic errors in 9 individual regional climate model simulations driven by the ERA-Interim reanalyses (Dee et al., 2011) and in the multi-model ensemble mean.]

Climate baseline information can also be derived directly from climate models, either global models or via downscaling of their outputs. Significant international activity on establishing the credibility of the climate simulations of these models is enabled through the coordination activities of the Coupled Model Intercomparison Project (e.g. CMIP5, Taylor et al., 2009) and has shown improvements in the quality of this information since AR4 (AR5-WG1 Chapter 9). The issue raised above of credibility of climate information from a resolution perspective is relevant here, though there has been some improvement since CMIP3/AR4 with many of the models now running at 100-150km resolutions. Again, this may be addressed by downscaling these simulations (which has been facilitated by improved data capture from the CMIP5 models for CORDEX, Giorgi et al., 2009) and the credibility of this information can be established by similar validation procedures (AR5-WG1 Chapter 9). In theory, one would expect that validation of a reanalysis downscaling should provide a more accurate picture of a models performance though this can be complicated by reanalysis errors (Cerezo-Mota et al., 2010) or differences between reanalyses (Mearns et al., 2012).

21.3.4.1.2. Non-climatic baselines

[forthcoming]

21.3.4.2. Uncertainties Regarding Future Climate

From the viewpoint of developing projections of long-term climate change, there are primarily three sources of uncertainty. This section discusses these three sources, comments on how the uncertainty has been quantified (if it has been), and indicates whether we can reasonably expect reductions in these sources of uncertainty.

21.3.4.2.1. Future emissions and concentrations of greenhouse gases and aerosols

Future climate forcing (derived from emissions and concentrations) will be shaped primarily by: emissions of greenhouse gases, aerosols, and short-lived species into the atmosphere; and processes that control the composition of the atmosphere, such as atmospheric chemistry, terrestrial and marine components of the carbon cycle, and nitrogen cycles. Factors that influence the scale of future anthropogenic emissions include the scale of economic activity, the technologies with which human societies generate and use energy, and the public policy environment in which human activities are conducted. Hence, predicting emissions of GHG and aerosols requires being able to predict how the entire human world will develop in the future, a truly daunting task fraught with multiple profound uncertainties. This would also include determining future populations, gross domestic product (GDP), and the development of future technologies. There is not much chance of reducing these uncertainties for the long-term future. There has been an understandable reluctance to quantify the uncertainty in the emissions of greenhouse gases and aerosols, although some elements contributing to final emissions estimates have been quantified, for example, of population. Nevertheless, future emissions have mainly been presented as scenarios having equal plausibility (Parson et al., 2007). This was the case with the SRES scenarios, and will be the case with the RCPs and SSPs (van Vuuren et al 2012, Adger et al 2011).

21.3.4.2.2. Climate system response to forcing

Climate system uncertainty is explored through the application of global and regional climate models. While most of these models are carefully constructed to incorporate many climate-related processes and are carefully evaluated, they do not necessarily respond in the same way to a given future forcing scenario. These differences are due to scientific uncertainties about how the climate system works, differences in the way various subsystems are modeled (e.g., land surface processes) and differences in how unresolved processes are parameterized (e.g., convection). These uncertainties are explored and characterized by analyzing the results of different types of ensembles of climate model simulations. The most common is the multi-model ensemble (MME) based on simulations with different climate models that are subjected to the same future radiative forcing. These MMEs play a central role in the analyses that contribute to the various IPCC assessments (e.g, sets of simulations from CMIP3 and CMIP5 for the AR5 Reports). There are also ensembles developed from a single climate model whose parameters are varied in systematic ways, which are referred to variously as Parameter Permutation Experiments or Perturbed Physics Ensembles (PPE) (e.g., Murphy et al., 2007).

While the climate models used to generate simulations for the AR5 are more complete than ever before (e.g., most now have fully closed carbon and nitrogen cycles, thus reducing the uncertainty regarding final concentrations in the atmosphere), there are still processes that are known to be important but are not incorporated due to incomplete understanding of the process or difficulty in modeling the process. For example, the CMIP5 models still do not include the explicit modeling of glacier and ice sheet dynamics. Hence, projections of sea level rise from such models are bound to be incomplete and therefore limited. Other such missing processes include possible occurrence of catastrophic events such as the collapse of the Greenland Ice Sheet. Another example is that the global climate models are still limited in terms of resolution which can be important for capturing relevant processes as demonstrated in a recent study with improved vertical resolution allowing better representation of the stratosphere which then significantly influenced the projected changes in the climate over Europe (Scaife et al. 2011).

Climate change projections from global climate models and any subsequent downscaling generally project a range of future temperature and sea-level rise, and in some cases, for example precipitation, the sign of the change may differ from one model to another. However, it is important to note that in many cases, the difference in direction of change in precipitation simulated by, for example, two different models, indicates a lack of significant change in the precipitation compared to the natural variability in a particular region (Tebaldi et al. 2011)

IPCC AR4 states clearly that temperatures and sea-levels are predicted to increase (i.e. providing quantified levels of confidence in the range these increases are expected to lie) and thus this information has high credibility. This is due to model simulations reproducing observed trends in these variables, an understanding of the physical drivers of these trends and that the models represent these well.

In other cases, model projections could be less consistent or inconsistent with available observations. In these cases, the projection information is less credible as explained in the following examples:

- In some cases drivers of historical change are not known so there is a lack of physically-based understanding of the past to use in the assessment of confidence in the models' ability to simulate regional climate change. An example of this is the reason for the significant drying trend seen in the Sahel from the 1960s to the 1990s. Whereas statistical analysis has demonstrated the role of sea-surface temperatures (SSTs) in driving Sahel rainfall variability, and some relevant mechanisms identified, models driven by observed SSTs fail to capture the full magnitude of the drying trend (e.g. Held et al. 2005). Thus our understanding of the system and its drivers is incomplete which complicates the interpretation of future projected changes in this region (e.g. Biasutti et al., 2009, Druyan, 2010). This implies that other processes are important and thus research is required to identify these and ensure that they are correctly represented in the models. Without knowing what these processes are and thus that the models are representing all relevant processes, projections of rainfall changes over this region cannot be considered reliable.
- A more extreme case is where future projections all go in the opposite direction to the observed changes and an example of this is seen over part of the continental US which has seen cooling trends in past few decades (AR4 WG1) though the projected changes indicate a warming. This is not necessarily a contradiction though the lack of similar cooling trends in many climate models again indicates there is a process which is not being captured in the models and needs to be identified and included in future. Then the influence of the process in projections of future climate change needs to be assessed in order to provide confidence in the sign and magnitude of any changes.

In these cases where future projections may differ significantly or go in opposite directions, it is still important to provide information on the range of changes. The likelihood that temperatures (and sea-level) will continue to rise in the future is sufficient to motivate a response to these predicted changes and, in general, information on other climate variables will also be required. Thus it is important to be able to characterize the range of plausible changes in these other variables.

One approach is to use a Bayesian probabilistic framework to combine the range of information that may include differences in direction of change in precipitation in a global climate model (e.g. Tebaldi and Knutti, 2007, Harriss et al., 2012) or in a global model and then a regional model driven by the global model (e.g., Déqué and Somot (2010); Sain, Tebaldi et al. (in progress) for the NARCCAP project). Another is to identify a subset of available models whose response characterises the range of projected futures (e.g. McSweeney et al., 2011).

It is expected that with model improvements (e.g., including more important processes and modeling processes more completely) that the uncertainty due to climate (model) response will be reduced over time in certain ways. However, this does not necessarily mean that all metrics of uncertainty will be reduced at once. It is quite possible that improving the representation of processes will not immediately result in reduction of uncertainties regarding the likely range of temperature change in central Kansas in 2050, for example (Mearns, 2010a,b). One of the FAQs presented in Chapter 1 of WG1 discusses this issue in more detail.

21.3.4.2.3. Internal variability

Long-term projections of climate change are subject to uncertainty resulting from the internal variability of the climate system. The relative role of this type of uncertainty compared to the other sources of uncertainty (climate model response uncertainty and forcing uncertainty), are a function of the future time horizon being considered and the spatial scale of analysis (Hawkins and Sutton, 2009; 2011). Here we use the term natural or internal variability to refer to unforced variability internal to the climate system. Hence this definition does not include variability related to the occurrence of natural phenomenon, such as volcanoes. Internal variability is usually explored by running sets of climate model simulations (ensembles) using different initial conditions for each simulation. Traditionally the number of ensemble members has not been large (e.g., around 3 in the CMIP3 data set), but the number has increased in the CMIP5 set of simulations to about 7. However, some recent research has explored larger numbers of ensemble members (e.g., Deser et al., 2010) and has thus come up with improved measures of natural variability. In this case 40 different members were produced, which represent how much the climate can vary based on random internal variations. The variations across ensemble members can be considerable on various spatial scales, and there is considerable evidence that this kind of uncertainty may not be particularly reducible. (Deser et al. 2012). The issue of internal variability is more thoroughly discussed in WG1 Chapter 12, section 12.1.1.2.

_____ START BOX 21-3 HERE _____

Box 21-3. Developing Regional Climate Information Relevant to Political and Economic Regions

In most world regions, countries form political and/or economic groupings and coordinate activities within these groups with stated aims such as furthering the interests of the constituent nations and their peoples. Such groupings provide a natural forum for coordinating action on transboundary issues within their region or responding to influences external to it. Climate is an important factor in the economies of many nations and the lives of their peoples and is well understand to have both transboundary dimensions and to involve remote influences. This has long been understood, national and regional weather-forecasting is highly dependent on globally coordinated activities, and more recently with the advent of the WMO-sponsored Regional Climate Outlook Fora. These links are also being made regionally. For example, the Intergovernmental Authority on Development (IGAD) of the countries of the Greater Horn of Africa (GHA) recognizes that the region is prone to extreme climate events such as droughts and floods which have severe negative impacts on key socio-economic sectors in all its countries. In response it has set up the IGAD Climate Prediction and Applications Centre (ICPAC) to provide and support application of early warning and related climate information for the management of climate-related risks (for more details see http://www.icpac.net/). Given that in the context of climate change, socio-economic factors (among others) are important contributors to both the vulnerability and adaptability of human and natural systems, it clearly makes sense to summarise and assess available climate and climate change information for these regions. This information is relevant to assessing socio-economic impacts and adaptation options and so would be relevant to policy decisions taken within these groupings on their responses to climate change.

Figure 21-6 presents summary climate change information for 6 political/economic regions covering much of Africa. These are the Indian Ocean Commission (COI), the Common Market for Eastern and Southern Africa (COMESA[6]), the Economic Community of Central African States (ECCAS), the Economic Community Of West African States (ECOWAS), the Southern African Development Community (SADC) and the Arab Maghreb Union (UMA). Each graph shows observed[7] and simulated variations in past and projected future annual average temperature and precipitation. Generally the observed regional temperature variations reflect global changes, with warming from 1901 to 1940, followed by a relatively stable period until 1970 and then steady warming thereafter. Consistent with simulations available for the AR4 (Christensen et al. 2007), the observed warming is contained within the envelope of the simulations of global climate models driven with observed changes in all known external drivers (pink band) in all six regions. The 1901-1940 warming in these simulations is partly distinguishable from what would have been expected if anthropogenic activities had not interfered with the climate, as estimated by simulations with observed changes in natural external drivers only (blue band). In all six regions there is a distinct difference by the beginning of the 21st century, which is projected to continue to widen if emissions broadly follow the SRES A1B or RCP4.5 emissions pathways (green band). In contrast, precipitation has generally remained steady, relative to its year-to-year variability, without major changes driven by anthropogenic emissions in either the past or future as estimated from the climate model simulations. Exceptions are an observed drying over ECOWAS between the 1960s and 80s (Greene et al. 2009, Hoerling et al. 2006) and a simulated drying of about 15% over the 150-year period over UMA. It should also be noted that, unlike temperature, observed precipitation variability sometimes lies outside the envelope of the simulations from the models though the simulated variability would be expected to be less, in general, due to it representing precipitation effectively averaged over larger areas than is represented by the sparse station data underpinning the observed estimates.

[INSERT FIGURE 21-6 HERE
Figure 21-6: Variations in past and future regional climate over Africa. Precipitation plots cover land territory only, while temperature plots cover both land and exclusive economic zone territory. Black lines show annual average values from observational datasets and coloured bands show the 10-90th percentile range of annual average values from 32 simulations from 12 climate models from the WCRP CMIP3 and CMIP5 projects (Meehl et al. 2007, Taylor et al. 2012). The pink band is from simulations driven with observed changes in all known external drivers over the 1901-2005 period. The blue band is from simulations driven with observed changes in natural external drivers only. The green band is from simulations running over 2006-2050 driven under either the SRES A1B or the RCP4.5 emissions scenario. Observed values are plotted as anomalies from their 1901-2005 averages. Model values are plotted as anomalies from their 1901-2005 averages in the simulation with all know drivers.]

[FOOTNOTE 6: Note that only the northern half of COMESA is represented here, starting with Rwanda, Uganda, and Kenya, as the countries in the southern half are contained within the SADC grouping. Also, Western Sahara and Somalia are not included in any region.]

[FOOTNOTE 7: The observational datasets used are GISTEMP (Hansen et al. 2010), HadCRUT3 (Brohan et al. 2006), and MLOST (Smith et al. 2008) for temperature, and CMAP (Xie and Arkin 1997), CRU TS 3.10 (Mitchell and Jones 2005), GPCP v2.2 (Adler et al. 2003), and PRECL (Chen et al. 2002) for precipitation. These suffer in some areas from sparse monitoring coverage.]

The information presented here is illustrative of an approach to presenting a simple summary of observed and projected or predicted climate changes for political/economic regions. In dealing with annual temperature and precipitation it averages over the annual cycle and thus does not present information on variations in seasonal averages which could be of particular importance in the case of precipitation. However, the graphs still convey important information on the ability of the models to reproduce the observed trends in temperature, that they simulate significantly lower temperatures without the anthropogenic forcings and how future temperatures under a typical business as usual emissions path will continue to rise. The main messages on precipitation are that for most regions the models project that future variations will be similar to those simulated for the past and that the models may not capture all of the observed precipitation variability. Without further refinement, this information would suggest that future precipitation scenarios should be significantly informed by the past observed variability. However, at least two additional factors should be taken into account. The first is that these results do not consider seasonal precipitation. Secondly, theoretical and model evidence indicates that it is not unreasonable to expect that in a warming climate many regions could experience changes in precipitation variability and extremes even with no changes in the average.

_____ END BOX 21-3 HERE _____

21.4. New Understanding and Emerging Knowledge on Climate Change

This section assesses advances in climate information relating to all aspects of the climate system and for all regions that are relevant to the study of climate change impacts and the assessment of vulnerability and adaptation to climate change. Vulnerability and adaptation assessments need to account for any non-climatic drivers which can influence the capacity of systems to adapt to climate change. Thus advances on understanding and information about these non-climatic drivers are also assessed. As assessments of vulnerability and adaptation require accounting for the influence of multiple climatic and non-climatic factors, an understanding of the uncertainties in information about these factors, how these can be calculated and how they should be used is essential. This issue is addressed at the end of the section.

21.4.1. Physical Science Research

Regional climate information in the AR4, both for recent past and future conditions, was mostly derived from a wide range of station and satellite observation products and from global model simulations participating in the CMIP3 experiments. Although results from both dynamical and empirical/statistical downscaling tools were available, they were still not comprehensive enough to provide a coherent picture of past and future regional changes with associated uncertainties. With the improvement of observing systems and the inception of coordinated global model and regional downscaling experiments, such as CMIP5 (Taylor et al. 2009) and CORDEX (Giorgi et al. 2009), improved regional scale information has become available. In addition, more targeted analysis of climate projections for impact assessment studies has been carried out in response to the need for better coordination across the climate and IAV communities (Giorgi et al. 2009). This section is not intended to provide a full assessment of all regional information available since the AR4, which can be found in the WGI report and in the WGII regional chapters of the AR5, but rather to assess new, changed or emerging knowledge concerning regional climate change information relevant to IAV work.

21.4.1.1. Atmosphere and Land Surface

21.4.1.1.1. Main conclusions from the AR4

Most regional information on observed trends and projections in the AR4 was included in Chapter 11 of the WGI report. Where possible, robust regional information was provided as based on multiple lines of evidence, although the primary source of this information was the CMIP3 ensemble. Overall the regional patterns of temperature and precipitation change projections in the AR4 were largely consistent with those found in the TAR, although with increased robustness over some regions. Concerning temperature, the AR4 conclusion was that it was very likely that most land regions would warm in the 21st century and likely that the warming would be greater than the global average warming. Observed continental-average warming trend in the latter half of the 20th century was also found (except over Antarctica), likely attributable to anthropogenic greenhouse gas forcing. Warm temperature extremes, such as summer heat waves, were projected to very likely increase in the 21th century over most land regions.

For precipitation projections, the main conclusions of the AR4 were (Christensen et al. 2007):

- Increase of precipitation over East Africa in the annual mean (likely); central Europe in winter (likely), northern Europe in winter and summer (very likely); northern Asia (very likely), Tibetan Plateau (very likely) and eastern Asia (likely)in winter, Northern Asia, East Asia, South Asia and most of South East Asia in summer (likely for all); Canada and northeastern USA in the annual mean (likely), southern Canada in the winter and Spring (both likely); Tierra del Fuego in winter and southeastern South America in summer (both likely); west of the South Island of New Zealand (likely); both Polar regions in the Annual and seasonal means (very likely).
- Decrease of precipitation over the Northern Sahara in the annual mean (likely), Southern Africa in winter (likely); Mediterranean in annual and seasonal means (very likely), Central Europe in Summer (likely); central Asia in summer (likely); southwestern USA in the annual mean (very likely), southern Canada in summer (likely); most of central America and the Southern Andes in the annual mean (likely), southern Australia in winter and spring (likely) and southwestern Australia in winter (very likely).

In addition, widespread increases of precipitation intensity and extremes were found in the latter part of the 20th century, especially in areas of precipitation increase, along with greater length and intensity of droughts (especially in areas of precipitation decrease). These general trends were projected to continue in the 21st century. The maximum intensity of tropical and extratropical storms was projected to mostly increase. Observed trends in mean precipitation for the 20th century showed a high level of variability, while more consistency was found in the observed increasing trends in precipitation intensity.

21.4.1.1.2. New understanding and emerging knowledge

Since the AR4 substantial additional regional analysis of the CMIP3 ensemble has been carried out. For example, Giorgi (2006), Diffenbaugh et al. (2008) and Xu et al. (2009) used different regional climate change indexes including changes in mean and interannual variability of temperature and precipitation to calculate end of 21st century climate change "hot-spots" at subcontinental and regional scales based on the CMIP3 archive accounting for multiple GCMs, scenarios and realizations. Among the most prominent hot-spots identified were the Mediterranean Basin, Central America, the Northern high latitude regions, the southwestern United States, and the Tibetan Plateau. Giorgi and Bi (2009) estimated the Time of Emergence (TOE) of prominent regional precipitation change hotspots, i.e. the time at which the precipitation change signals projected by the models would exceed the underlying uncertainty, and found TOE in the early decades of the 21st century for the northern high latitudes (positive change), Mediterranean (negative change) and East Africa (positive change), mid-decades in East and South Asia (positive change) and Caribeban (negative change), and in the late decades in the Western United States, Central America, Southern Africa, Amazon Basin and Southern Australia (al negative changes). More recently Diffenbaugh and Scherer (2011) found from the CMIP3 ensemble that tropical regions, and in particular Central Africa and Southeast Asia would have the most rapid and permanent transition (order of 4 decades) into a new heat regime in which the coolest warm season of the 21st century is hotter than the hottest warm season of the late 20th century.

In a recent paper Harris et al. (2012) used a Bayesian method complemented by pattern scaling and performance-based model weighting to calculate Probability Density Functions (PDFs) of temperature and precipitation change over sub-continental scale regions (Figure 21-7) under the A1B emission scenario based on an ensemble of simulations constrained to observations for the late 21st century. Warming is projected over all regions, while regions of precipitation increase and decrease are found. Of particular use for impact assessment studies is the identification of the evolution of different percentiles of the distribution, information that can be used for risk assessment studies. Pattern scaling is indeed a valuable tool to estimate mean regional changes and associated uncertainty. For example, Giorgi (2008) proposed a simple equation to calculate regional temperature and precipitation changes based on global temperature projections.

[INSERT FIGURE 21-7 HERE
Figure 21-7: Evolution of the 5%, 17%, 33%, 50%, 66%, 83% and 95% percentiles of the distribution functions for annual surface air temperature changes (upper panel) and annual precipitation (lower panel) for the Giorgi-Francisco (2000) regions and the globe with the A1B forcing scenario. Twenty year means relative to the 1961-1990 baseline are plotted in decadal steps using a common y-axis scale. The 5%, 50% and 95% percentile values for the period 2080-2099 are displayed for each region. (From Harris et al. 2012)]

Some regional analyses of the CMIP5 ensemble have been carried out. In general the temperature and precipitation change patterns in the CMIP5 ensemble are similar to those found for CMIP3, with a pattern correlation between CMIP5 and CMIP3 ensemble mean change patterns greater than 0.9 for temperature and greater than 0.8 for precipitation (WGI Chapter 12). This implies that the regional characteristics of change in the CMIP5 ensemble lead to conclusions generally consistent with those found in the AR4. Given the increased comprehensiveness and higher resolution of the CMIP5 models this adds an element of robustness to the projected changes.

Compared to CMIP3, CMIP5 places greater emphasis on near-term climate change, including intitialized experiments aimed at assessing decadal predictability. The uncertainty in near term projections is dominated by internal variability, initial ocean conditions and inter-model response, rather than GHG forcing, and in fact the internal variability grows in importance at smaller spatial and temporal scales (Hawkins and Sutton 2009, 2010). Conversely GHG forcing uncertainty becomes increasingly important on longer time scales, especially for surface air temperature (Hawkins and Sutton, 2009, 2010). Global warming for the period of 2016-2035 compared to 1986-2005 based on the CMIP5 multi model ensemble is 0.6-0.7ºC for four RCPs, with a warming trend of 0.14-0.25K/decades (WGI Chapter 11). Differences across RCPs are small and 50% of the warming is understood as the committed response to past emissions (WGI Chapter11). As for long term projections, near term temperature projections in the CMIP5 ensemble are generally consistent with those in the AR4, with warming being greater over land than over ocean (WG I Chapter 11). Precipitation is found to increase in the tropics and high latitudes and decrease in the dry region of tropics and sub-tropics (WGI Chapter I). The near term magnitudes of change show large inter-model spread and are smaller than the magnitude of internal variability in some regions (WGI Chapter 11).

The CMIP5 ensemble includes a new set of multidecadal near term prediction experiments (up to 2035) with initialized ocean state (WGI Chapter 11). First preliminary analyses of these experiments show that over land the predictability of internally generated surface temperature decadal changes is generally low. Predictability is higher over the oceans, especially in middle and high latitudes of the North Atlantic, North Pacific and Southern Oceans due to deep ocean mixed layers ocean currents in these regions. The predictability of not externally forced regional rainfall patterns for the next decades is very low. There are indications that the Atlantic Meridional Overturning Circulation (AMOC) exhibits decadal predictability with lead-time varying from model to model and ranging from several years to ten years. Some predictability of Pacific Ocean SST spatial patterns of up to 6-10 years is indicated by some studies (WGI Chapter 11).

A new climate change hot-spot analysis of the CMIP5 ensemble was carried out by Diffenbaugh and Giorgi (2012), who extended the methodology of Giorgi (2006) and Diffenbaugh et al. (2008) by adding metrics of seasonal extremes and considering the temporal evolution and emergence of hotspots (Figure 21-8). They found that the Amazon, the Arctic, the Sahel and tropical West Africa, and the Tibetan Plateau are persistent regional climate change hotspots which emerge early in the 21st century of the RCP8.5 forcing pathway and persist throughout the rest of the century, suggesting that they are robust to varying levels of global warming. Areas of southern Africa, the Mediterranean, and Central America/western North America also emerged as prominent regional climate change hotspots in response to high levels of forcing. This contrasting persistence and emergence of hotspots in response to increasing radiative forcing highlights the relevance of regional climate heterogeneity for climate change mitigation and adaptation strategies.

[INSERT FIGURE 21-8 HERE
Figure 21-8: The relative aggregate climate change between the 1975-2005 period and the 2010-2039, 2040-2069 and 2070-2099 periods of RCP8.5. The aggregate climate change is calculated using the Standard Euclidean Distance (SED) across the 28-dimensional climate space formed by 7 climate variables in each of 4 seasons. The absolute values of change in each variable are normalized to the maximum global absolute value prior to calculating the SED. The SED values are then normalized to the maximum global SED value. Only land grid points north of 60˚S are used in the normalizations (From Diffenbaugh and Giorgi 2012).]

Concerning projected changes in the Earth's hydrologic cycle, based on an analysis of observations, global and regional climate model simulations, Giorgi et al. (2011) defined an index of hydroclimatic intensity (HY-INT) incorporating a combined measure of precipitation intensity and mean dry spell length. They found that a ubiquitous global and regional increase in HY-INT was a strong hydroclimatic signature in model projections consistent with observations for the late decades of the 20th century, suggesting that HY-INT may be an important hydroclimatic indicator of global warming for use in detection/attribution and impact studies. The increase in intensity of precipitation (and thus risk of flood) and summer drought occurrence over mid-continental land areas is a robust signature of global warming, both in observations for recent decades and in model projections (Trenberth 2011). Concerning projections of temperature extremes, the CMIP5 ensemble confirms results from the CMIP3, namely a decrease in the frequency of cold nights, and an increase in the frequency of warm days and nights, duration of heat waves.

Concerning tropical cyclones, there is still little confidence in the past trends and near term projections of tropical cyclone frequency and intensity (Senevirante et al 2012). The global tropical cyclone frequency is projected to either not change or decrease and at the basin scale (Knutson et al. 2010). In addition, regional circulations, such as the monsoon, are expected to change. Seth et al. (2011) and Sobel and Camargo (2011) found in the CMIP3 ensemble of 21st century projections a redistribution of precipitation from spring (early monsoon phase) to summer, mature phase in both northern (North America, West Africa and Southeast Asia) and southern (South America, Southern Africa) hemisphere monsoon regions. More generally, model projections indicate a decreased intensity of monsoon circulation, but an increase of monsoon rain due to the greater water-holding capacity of the atmosphere (WGI Chapter 14).

21.4.1.1.3. Major Modes of Variability
(Cross Reference to Chapter 11 of WG1)

There are many large-scale modes of climate variability relevant to climate impacts and adaptation, e.g El Nino/ Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), Southern Annular Mode (SAM), Indian Ocean Dipole (IOD) (see AR5-WG1 Chapter 14 for a complete discussion). There is no evidence that these will cease to exist with continued climate change, but some of their characteristics may change which could result in impacts and the need for adaptation. For example, changes in the frequency and intensity of ENSO would affect drought frequency in eastern Australia and rainfall patterns in the US. Similarly changes in the IOD could influence the frequency and intensity of droughts in Indonesia and floods in East Africa. Here new findings on the major modes of variability relevant to vulnerability, impacts and adaptation research are assessed (see AR5-WG1 Chapter 14 for more complete coverage of new climate science findings).

ENSO is the mode of variability that has received most attention from a climate impacts point of view with significant effects on human and natural systems (http://iri.columbia.edu/climate/ENSO/societal/index.html). Seasonal forecasting of El Nino behavior has significant skill (AR4-WG1 Chapter 8) and is used to providing advanced warnings of its impacts worldwide. Recent research has underscored the complexity of the ENSO system and provided some explanation for this, such as the non-symmetric amplitude between El Nino and La Nina (An, 2005). While we do not have definitve answers regarding the effect of anthropogenic forcing on ENSO, we know that it experiences decadal and longer term modulations that occur with relatively small changes in the mean climate state of the tropical Pacific. Model improvements in the reproduction of ENSO are evident in some of the models used for the CMIP5 simulations. For example CCSM4 better reproduces the asymmetry between El Nino and La Nina durations (Deser et al., 2011).

Europe

Numerous climate change projection assessment studies over the European region have been carried out, not only from global model simulations, but also from intercomparison projects such as PRUDENCE (Christensen et al. 2007; Deque et al. 2007) and ENSEMBLES (Hewitt 2005; Deque and Somot 2010). They all provide a generally consistent picture of seasonally and latitudinally varying patterns of change, which Giorgi and Coppola (2007) summarized with the term “European Climate Change Oscillation (ECO)” (Figure 21-9). This consists of an area of maximum warming over the Mediterranean in summer moving to Northern Europe in winter. A dipole pattern of precipitation change, with decreased precipitation to the south and increased to the north, also follows this latitudinal/seasonal oscillation, being centered over the Mediterranean in winter and moving to central Europe in summer. As a result, the Mediterranean region is projected to be much drier and hotter than today in the warm seasons (Giorgi and Lionello 2008), and central/northern Europe much warmer and wetter in the cold seasons (Kjellstrom and Ruosteenoja, 2007). An increase of interannual variability of precipitation and summer temperature is also projected throughout Europe, with a decrease in winter temperature variability over Northern Europe (Schar et al. 2004; Giorgi and Coppola 2007; Lenderink et al. 2007). The broad patterns of change in regional model simulations generally follow those of the driving global models (Christensen and Christensen 2007; Deque et al. 2007), however fine scale differences related to local topographical, land use and coastline features are produced. For example, east-west winter precipitation change dipoles are projected across the Appenine chain as a result of the effect of this mountain system (Gao et al. 2006; Coppola and Giorgi 2010). A broad range of climate extremes are projected to increase over different European regions (Beniston et al. 2007), such as heat waves, maximum drought length and number of hot days, especially over Central and Southeastern Europe and the Mediterranean (Gao et al. 2006; Beniston et al. 2007; Kjellstrom et al., 2007; Diffenbaugh et al., 2007), precipitation intensity and extremes especially over Central, Western and Northern Europe (Frei et al. 2006; Beniston et al. 2007, Buonuomo et al. 2007; Fowler et al. 2007; May 2008; Fowler and Ekstrom 2009; Kysely and Beranova, 2009; Kendon et al. 2010; Hanel and Buishand 2011; Kysely et al. 2011). Studies have also consistently shown that the distribution of seasonal temperature anomalies in the future is expected to be much broader than today. This will lead, along with a shift of the distribution, to a higher frequency and intensity of extreme hot and dry summers (e.g. Schar et al. 2004; Seneviratne et al. 2006; Beniston et al. 2007; Coppola and Giorgi 2010), for which a substantial contribution is given by land-atmosphere feedbacks (Seneviratne et al. 2006; Fischer et al. 2007; Seneviratne et al. 2010; Hirschi et al. 2011; Jaeger and Seneviratne 2011). In general, the Mediterranean region is consistently projected to be much more arid than today (Rowell and Jones 2006; De Castro et al. 2007; Giorgi and Lionello, 2008; Gao and Giorgi 2008; Onol and Semazzi 2009; Trnka et al. 2011), and coupled atmosphere-ocean RCM simulations indicate that ocean feedbacks can significantly amplify the regional climate change signal over different regions of Europe (Somot et al. 2008). Concerning storminess projections , some studies based on ensembles of RCM simulations indicate a prevailing increase in winter mean daily and peak wind speed over Northern Europe (Rockel and Woth 2007; Albrecht et al. 2010, Bengtsson et al. 2009), while more mixed results are found over the Mediterranean (Lionello et al. 2008; Giorgi and Lionello 2008).

[INSERT FIGURE 21-9 HERE
Figure 21-9: Monthly values of the zonally averaged changes in mean surface air temperature (top left panel), temperature interannual variability (as measured by the standard deviation, top right panel), mean precipitation (bottom left panel), precipitation interannual variability (as measured by the coefficient of variation) over Europe; CMIP3 ensemble, A1B scenario, 2071-2100 minus 1961-1990. Units are degrees C for temperature and % of 1961-1990 values for mean precipitation (the coefficient of variation is unitless). The zonal average is taken over the region between 10°W and 25°E. The dashed lines illustrate the European Climate Change Oscillation (ECO). From Giorgi and Coppola (2007).]

Africa

Except for the East and Southern Africa regions, the CMIP3 ensemble of models showed a wide scatter of precipitation projections, so that robust conclusions were quite difficult in the AR4. As part of the ENSEMBLES and AMMA projects, 9 RCMs were run for the period 1990-2050 (A1B scenario) over domains encompassing the West Africa region with lateral boundary conditions from different GCMs. The RCM-simulated West Africa monsoon showed a wide range of response in the projections, even when the models were driven by the same GCMs (Paeth et al. 2011) (Figure 21-10). This along with the fact that the model biases were not strongly tied to the driving GCMs indicated that for Africa, and probably more generally the tropical regions, local processes and how they are represented in models play a key factor in determining the precipitation change signal. Similar conclusions were found for an all-Africa RCM simulation of 1980-2100 (A1B scenario) by Mariotti et al. (2011) as well as a climate change projection over South Africa with a variable resolution model (Engelbrecht et al. 2009). Diallo et al. (2012) showed that ensemble averaging of RCM simulations tends to compensate systematic errors from the individual models and provide more consistent results. They found a prevailing decrease in peak monsoon rainfall over the western Sahel for the early decades of the 21st century in an ensemble of 4 RCM simulations driven by different GCMs. These results indicate that uncertainties in projections of the hydrologic cycle of Africa remain high and need large ensembles of model simulations in order to be fully characterized.

[INSERT FIGURE 21-10 HERE
Figure 21-10: Linear changes of annual precipitation during the 2001-2050 period from 10 individual RCM experiments and the MME mean under the A1B emission scenario. The top middle panels also account for projected land cover changes (see text for further explanation). Note that the REMO trends in both panels arise from a three-member ensemble whereas all other RCMs are represented by one single simulation. Trends statistically significant at the 5% level are marked by black dots. (From Paeth et al. 2011)]

Statistical downscaling techniques have also been applied to the Africa region (Hewitson and Crane 2006; McKellar et al. 2007; Lumsden et al. 2009; Steynor et al. 2009). In general, methodological developments since the AR4 have been limited (see, for example reviews in Paeth et al., 2011, and Brown et al., 2008) and activities have focused more on the applications (e.g. Mukheibir, 2007, Nawaz et al, 2007, Gerbaux et al, 2009) for regional specific activities in the context of IAV work. Some promising developments relate to combining dynamical and statistical approaches, as for example in Paeth and Diederich (2010), who use an extended weather generator to optimize inputs to a hydrological model for application in west Africa. New work is also emerging that is not specific to Africa, but inclusive of all terrestrial regions. For example, Benestad (2011) developed a global downscaled product for station locations across all continents based on CMIP3, and draws a range of conclusions for regions including

Africa, although the robustness of the statistical downscaling relationship for a number of locations is weak. Other activities are underway for similar globally extensive downscaling based on new CMIP5 GCMs with the purpose of producing gridded products.

However, the majority of statistical downscaling has been related to application of existing data products and is mostly not reported in the peer reviewed scientific literature, being found instead in the grey literature of project and institutional reports. This reflects a parallel growth in dissemination of high resolution data products through web portals that are more properly associated with pattern scaling approaches, as opposed to what would more formally be considered downscaling. Collectively these activities reflect an application focus predicated on the era of the CMIP3 GCM.

Latin America

For the South America continent, the CMIP3 ensemble shows a prevailing signal of decreased precipitation over the Amazon basin in JJA, where large warming also occurs, increased precipitation in the La Plata Basin in DJF and decreased precipitation in Southern South America. Several RCM experiments have been conducted for the South America continent, also as part of the CLARIS project Menendez et al. 2010; Nunez et al. 2009; Sorensson et al. 2010; Marengo et al. 2009, 2010), and time-slice high resolution GCMs have been analyzed over the continent (Kitoh et al. 2011). In addition, pattern scaling was used to produce climate change scenarios over Southern South America (Cabre et al. 2010). Overall these studies revealed varied patterns of temperature and precipitation change, depending on the global and regional models used, however a consistent change found in many of these studies was an increase in both precipitation intensity and extremes, especially in areas where mean precipitation was projected to also increase.

The Central American region has emerged as a prominent climate change hot-spot since the AR4, especially in terms of a consistent decrease of precipitation projected by most models. Studies focusing specifically on Central America projections are still sparse, however Rauscher et al. (2008) analyzed an ensemble of CMIP3 global model projection over the region and found that most of the precipitation reduction there occurred in June-July, just before the August mid-summer drought. Their analysis indicated an early onset and intensification of the mid-summer drought in response to a westward expansion and intensification of the North Atlantic sub-tropical high associated with SST anomalies over the Tropical North Atlantic region and warm ENSO event like patterns in the eastern tropical Pacific (Rauscher et al. 2011). Also, Campbell et al. (2010) performed a downscaling study on two GCMs demonstrating warming over the land significantly greater and more consistent than the SST increases from the driving models and some robust precipitation changes, a general drying in June-October and the northern Caribbean getting wetter and the southern Caribbean drier in November–January.

North America

Results from the CMIP3 set of global projections over the North American region indicated distinct patterns of change in both temperature and precipitation on a seasonal basis (Christensen et al., 2007). Temperature increases are expected to exceed global mean warming in most areas and seasons. Greatest warming will tend to occur over the northern parts of the continent in winter and in the southern part of the continent (e.g., southwest US) in the summer. Annual mean precipitation is expected to increase in Canada and the Northeast US and to decrease in the southwest US. Snowpack throughout the continent is expected to decline (e.g., Brown and Mote, 2009).
The results published in the AR4, regarding both temperature and precipitation change still hold based on the CMIP5 simulations (Christensen et al., 2012, Chapter 14 WG1) on the broad continental scale, with precipitation increases dominating the northern third of the continent and drying in the southern third. Projections with AR5 models also indicate a poleward shift in wintertime storm activity as was found in the AR4 results.

Further investigation of the southwest US confirms earlier reports of continued drying through the 21st century, resulting from poleward expansion and intensification of the subtropical dry zones (Seager and Vecchi, 2010). However, there remains a lack of clear information on how relevant SST modes in the adjacent ocean might change

(Seager and Vecchi, 2010). The AR5 simulations show a reduction in precipitation in the core zone of the NAM (northern Mexico). Changes in precipitation in other regions of North America remain less clear, for example in the US Southeast, where there is little inter-model agreement. Summer precipitation change east of the Rockies is also unclear in the AR5 simulations, with little model agreement, likely due to the model weaknesses in simulating convection (Ruiz-Barradas and Nigam, 2006, 2010). The decline in snowpack seen with the CMIP3 models is also exhibited in the CMIP5 models (Diffenbaugh et al., in preparation).

Changes in extreme events remain an important feature of climate change for any region. Over North America, a number of the trends seen more generally are exhibited. Maximum and minimum temperature extremes are expected to increase, as well as daily precipitation extremes (Seneviratne et al., 2012). Uncertainties remain regarding changes in the frequency and intensity of tropical cyclones, although there is evidence from modeling studies that extreme wind speeds of tropical cyclones would increase. These expected changes in extremes have remained consistent from CMIP3 to CMIP5.

Since the AR4 there has been considerable attention given to producing higher resolution future projections of climate change over North America through the application of regional climate models (RCMs) and higher resolution time global time slices. In this context the research usually contrasts RCM and GCM changes in climate and tries to demonstrate the added value or greater credibility of the regional model future projections. For example, Liang et al. (2008) investigated bias propagation from current to future climate simulations over the US and Mexico by nesting two different versions of the CMM5 regional model in two different GCMs for 10 summers (current and future) They established that the uncertainty of future climate projection for RCMs or GCMs is very sensitive to the existence of present climate biases. The RCMs consistently reduced the biases present in the GCMs.

The North American Regional Climate Change Assessment Program (NARCCAP) has been a major multi-institutional effort using a number of different RCMs (with a resolution of 50 km) driven by different global climate models (GCMs) from the CMIP3 dataset, over the domain of most of North America (Mearns et al., 2009; 2012a). In this program only the A2 SRES emissions scenario was used for the time periods 1971-2000 and the future period 2041-2070. The program also included the development of several time slices: two using the GFDL AM2.1 atmospheric model at resolutions of 50 and 25 km, and one (50 km) using the NCAR atmospheric component of the CCSM3. Results so far indicate considerable variation in future climate based on the different RCMs, even when driven by the same GCM (Figure 21-11). In winter there tends to be more agreement across the GCMs and the RCMs for precipitation compared to in the summer, when the RCMs tend to depart more distinctly from the future projections of the GCMs (Mearns et al., 2012b). This suggests a distinct lack of robustness in the projected precipitation changes in summer. There is also a tendency for the uncertainty across the driving GCMs to dominate for winter temperature and precipitation, but the uncertainty across the different RCMs dominates in the summer season. More detailed investigations of subregions of the NARCCAP domain have now been performed. For example, Solowski and Pvelski (2012) explored the southeastern portion of the domain and applied a weighting scheme to the regional model simulations analyzed. They found the weighting scheme reduced the uncertainty in temperature change. For precipitation they found that the changes in precipitation, with the weighting scheme did not emerge above the level of natural variability. This result is consistent with global model results from both AR4 and AR5 wherein precipitation change results are highly uncertain. Rawlins et al. (2012) in a similar investigation of NARCCAP projections of climate change for the Northeast US found temperature changes across the models to be about 2 deg C and beyond the range of natural variability. Precipitation increases in winter were also found to be significant. Bukovsky et al. (in preparation) investigated the behavior of the NARCCAP models with regard to the North American Monsoon and was able to separate out the effects of the driving GCMS and the RCMs regarding error propagation. The GCM-RCM combinations that better produced the monsoon characteristics tended to indicate decreases in monsoon rainfall.

[INSERT FIGURE 21-11 HERE
Figure 21-11: Change in summer (JJA) average temperature (2041-2070 minus 1971-2000) from (top left) the NCAR CCSM3, (top right) the MM5 regional climate model driven by the CCSM3; (bottom left) the WRF model, driven by CCSM3, and (bottom right) the Canadian CRCM, driven by CCSM3. Temperature is in °C. Data from the NARCCAP program. (From Mearns et al., 2009, 2011)]

Other regional modeling efforts include those of Hostetler (in preparation), who has produced simulations with RegCM3 nested in several GCMs from CMIP3, one for the full transient of the 21st century using ECHAM5 as the nesting model. Caya and Biner (2011) have produced transient runs with the Canadian regional model (CRCM) at a 45 km resolution over a domain similar to that of NARCCAP, nesting in several different realizations of the CGCM3 GCM for the A2 scenario. They found evidence for significant differences in the climate change produced across the different realizations There has also been a series of more focused smaller domain applications of regional models over California (Subin et al. 2011), the Northwest (Salathé et al., 2008, 2010), the southwest (Dominguez et al. 2010), and the Great Lakes region (Lofgren et al., in preparation). While all these regional modeling efforts have produced interesting results, and some have further advanced the notion of model credibility, none have truly established across-the-board superiority of the regional model simulations regarding future climate. Further research into how to establish credibility of simulations of future climate is required (both for regional and global modeling).

In the realm of statistical downscaling and spatial disaggregation, considerable efforts have been devoted to applying techniques for the entire US, and parts of Canada (e.g., Maurer et al., 2007; Hayhoe et al., 2010). These methods are particularly useful for driving impacts models, since they are produced at very high resolutions (e.g., 10 km), but usually only include temperature and precipitation. Comparisons among the spatial disaggregation techniques and dynamical downscaling are underway including the differential effects on impacts and adaptation planning (e.g., Barsugli et al., in progress).

Asia

Large warming trends were found in northern Asia during winter (> 2^{o}C per 50 years) in the second half of the 20th Century (Christensen et al., 2011). The warming trend is about 1.8^{o}C over the past 60 years in Mongolia (Cruz et al., 2007), and over the past 50 years in the Tibetan Plateau (Wang et al., 2008). Over Korea (Kwon, 2005) and Japan (Fujibe, 2009), increasing temperature trends are 1.8^{o}C and 3.1^{o}C per Century, respectively, associated with both global warming and Urban Heat Island (UHI) effects. Air temperatures in Sri Lanka and India have increased by 0.3^{o}C and 0.48^{o}C respectively over the last 100 years, and average temperature increase in south Asia is about 0.1~0.3^{o}C per decade for the past 50 years (USAID, 2010). Widespread increasing trends for heavy precipitation were found in the AR4, but regional features of precipitation are quite variable depending on seasons, regions, and analysis period. Long-term trend of observed precipitation in many areas shows opposite trends between the 1901-2010 and 1979-2010 periods (WGI Chapter 14). There are no systematic regional trends in total precipitation as well as frequency and duration of extreme precipitation over Asia-Pacific regions (Choi et al., 2009). Nevertheless, there are statistically significant observed positive and negative precipitation trends at sub-regional scales within these regions. For example, a positive trend was found in Japan during 1901-2004 (Fujibe et al., 2006), in South Korea during 1973-2005 (Chang and Kwon, 2007), and in India (Krishnamurthy et al., 2009). Both positive and negative trends are found in China (Zhai et al., 2005; Yao et al., 2008), and in the Tibetan Plateau (You et al., 2008).

GCMs tend to project a consistent pattern of increased monsoon precipitation over both the East and South Asia regions throughout the 21st century, despite a general decrease of intensity of monsoon flow (e.g. AR4, Giorgi and Bi 2005). Numerous high resolution RCM projections have been carried out over the East Asia continent, and some of these tend to produce results that are actually not in line with those from GCMs. For example, Ashfaq et al. (2009) used an RCM with 25 km grid spacing to find that enhanced greenhouse forcing resulted in a predominant suppression of South Asia summer monsoon precipitation, a delay in monsoon onset and a an increase in monsoon break periods. These were mostly attributed to a weakening of the monsoon flow and a suppression of the dominant intraseasonal oscillatory modes. As another example, Gao et al. (2011) completed a climate projection at 20 km grid spacing over East Asia and found that while the forcing GCM produced a prevailing increase in summer monsoon precipitation, in agreement with most GCM-based projections, the nested RCM showed large areas of decreased summer precipitation amounts in response to the high resolution topographical forcing of the Tibetan Plateau and other topographical complexes. Similarly a series of double nested RCM scenario simulations were performed for the Korea peninsula reaching a grid spacing of 20 km (Im et al. 2007a; 2008a,b; 2010; 2011a,b). They indicated a complex fine scale structure of the climate change signal, particularly for precipitation, also forced by local topographical features and a consistent increase in intense and extreme precipitation events.

All these high resolution RCM experiment do point out the importance of regional and local topographical forcings in modulating the response of regional circulations, e.g. the monsoon, and of local phenomena, e.g. tropical convection. This adds a considerable level of uncertainty to projections of regional to local climate change which needs to be characterized by large ensembles of simulations.

Australia

The CMIP3 models produced a consistent decrease of precipitation over southwestern Australia in winter and summer, and southern and southeastern Australia in winter, along with a substantial warming in the inland regions of the continent (and especially the western portion) in all seasons. Suppiah et al. (2007) produced an updated assessment of the CMIP3 ensemble by analyzing the top 15 CMIP3 models in terms of their ability in simulating present day temperature, precipitation and sea level pressure. Use of this sub-ensemble essentially confirmed the full ensemble results, although some sub-regional detail changed. Both RCM and variable resolution model experiments have been conducted over the Australian continent or some of its sub-regions (Watterson et al. 2008; Nunez and Mc Gregor 2007; Song et al. 2008), showing that a local fine scale modulation of the large scale climate signal occurs in response to topographical and coastal forcings.

Statistical downscaling has been applied for a number of focused studies over Australia. Timbal et al (2008) evaluate the consistency between statistical downscaling and projections from the GCMs using two different statistical downscaling methods. They find that along with the higher resolution of the downscaling, the downscaled and direct model projections are largely consistent across the 15 GCMs used, and averaged across the southwest of Western Australia indicate a general decline of precipitation. More recently Yin et al (2010) focus on new methodological developments in downscaling, using an adapted Self Organizing Map procedure based on Hewitson and Crane (2006), and in common with other statistical downscaling studies finds the most notable challenge is downscaling precipitation in arid zones.

21.4.1.2. Oceans and Sea Level

Contributions to sea level rise include thermal expansion, glacier and ice cap melting, Greenland ice sheet and Antarctic ice sheet melting. Regional sea level change can be quite different from global sea level change due to changes in circulations and associated wind stress.

21.4.1.2.1. Main conclusions from the AR4

The AR4 concluded that global average sea level rose at a mean rate of 1.8 [1.3 to 2.3] mm/year over the period 1961 - 2003, with a faster rate of 3.1 [2.4 to 3.8] over 1993 – 2003. The total estimate 20th century sea level rise was 0.17 [0.12 to 0.22] m. Marked regional variability of sea level change during the late 20th century was observed from satellite data, with areas exhibit greater than average rise and others less than average rise or even decline. The largest contributions to sea level rise were assessed to be from thermal expansion and glaciers and ice cap melting. The sum of the estimated contributions to sea level rise was however lower than the observed rise, denoting a substantial uncertainty in the estimated components. Insufficient evidence was found concerning observed changes in the Atlantic Meridional Overturning Circulation (AMOC).

Model-based projections of global average sea level rise for the 21st century under the six SRES marker scenarios were in the range of 0.18 – 0.59 m (2090-2099 relative to 1980-1999). These estimates excluded future rapid dynamical changes in ice flow due to the lack of understanding of these processes, therefore the sea level rise estimates were characterized by a relatively high level of uncertainty. The AMOC was projected to very likely slow down in the 21st century, with a multi-model average reduction by 2100 of 25% [0 to about 50%] for SRES emission scenario A1B. It was estimated to be very unlikely that the MOC will undergo a large abrupt transition during the 21st century.

21.4.1.2.2. New understanding and emerging knowledge

Upper ocean warming since 1970 exceeding 0.1 degrees per decade has been observed based on independent measurements, decreasing to about 0.017 degrees per decade at 700 m depth (WGI Chapter 3). At the same time, the mean regional pattern of sea surface salinity has been enhanced with saline surface waters in the evaporation-dominated mid-latitudes becoming more saline, and relatively fresh surface waters in rainfall-dominated tropical and polar regions becoming fresher. Better understanding of ice flow dynamics was achieved along with better modeling of these processes, which resulted in improved estimates of global sea level rise. An improved set of observations, in particular the GRACE satellite data, is available. The observations of global mean sea level (GMSL) were extended to 2009, and they indicate a GMSL rise since 1900 of 1.7 +/- 0.2 mm/year with a maximum increase rate since 1990. Since the early 1970s, about 40% of observed GMSL rise is from ocean warming and about 35% from glacier melting. Both Greenland and the Antarctic Ice sheet have had small contributions to GMSL rise since the 1970s, however their contribution has been sharply increasing since the 1990s. New estimates of the different contributions to GMSL rise are significantly different from the AR4, and in particular the estimated sum of all contributions is closer to the observed values than in the AR4.

Evidence is strong that the biogeochemical state of the ocean has changed (WGI Chapter III). The ocean inventory of anthropogenic carbon dioxide has increased, from 114 ± 22 PgC in 1994 to 151 ± 26 PgC in 2010 and this is in broad agreement with the expected change resulting from the increase in atmospheric CO2 concentrations and change in atmospheric O2/N2 ratios (WGI Chapter 3). The uptake of CO2 by the ocean has resulted in a gradual acidification of seawater, with observations showing declines in pH in the mixed layer between -0.0015 and -0.0024 yr^{-1}.

Concerning GMSL projections (WGI Chapter 13), under all the RCP scenarios, the time-mean rate of GMSL rise during the 21st century is very likely to exceed the rate observed during 1971–2010, with ocean thermal expansion and glacier melting likely to make the largest contributions to this rise. For the period 2081 to 2100 compared to 1986 to 2005, GMSL rise is likely to lie in the range 0.27–0.50 m for RCP2.6, 0.32–0.56 m for RCP4.5 and RCP6.0, and 0.41–0.71 m for RCP8.5. The upper end of this range is higher than in the AR4, but the confidence in these estimates is still limited due to limited understanding of some key processes, such as rapid changes in ice sheet dynamics and the differences between estimates with semi-empirical and process-based models, with the former giving higher upper estimates (higher than 1.0 m).

Projections of regional sea level changes, both based on the CMIP3 and CMIP5 models, indicate a large regional variability of sea level rise, with areas undergoing much larger or smaller rise than the global average in response to different forcings, such as changes in wind stress and ocean circulation (WGI Chaapter 13). Regional sea level changes for the next decades will largely be dominated by internal dynamical variability of the climate system, while on longer time scales changes in regional sea level will likely be dominated by changes in ocean dynamics. Some preliminary analysis of the CMIP5 ensembles, for example, indicates area of maximum steric sea level rise in the Noerthern Atlantic, the northwestern Pacific off the East Asia coasts, the eastern coastal oceanic regions of the Bay of Bengal and the western coastal regions of the Arabian Sea (WGI Chapter 13).

Concerning storm surges and extreme sea level events, some analysis of the past decades indicate that the increase in such events is generally in line with the increase in mean sea level (Menendez and Woodworth 2010; Lowe et al. 2010; Woodworth et al. 2011). Dominant modes of variability, such as ENSO and the NAO, are also found to significantly affect extreme sea levels in a number of regions (Lowe et al. 2010). Some low lying areas, such as Venice (Carbognin et al. 2010) and the deltaic regions of the Bay of Bengal (Unnikrishnan and Shankar 2007), show trends in sea level much higher that the global average. Positive wave height trends are found in many areas of the North Atlantic, North pacific, U.S. coasts and Southern ocean, with modulation associated with main modes of climate variability. Projections of storm surges in European coasts have used RCM-produced wind fields to force storm surge models, and prevailing increases in extreme storm surges were found (Debernard and Roed 2008; Wang et al. 2008). However changes in storm surges are tied to changes in atmospheric circulations, and may be highly regionally dependent. Increase of global mean sea level is also likely to result in increase of storm surges and extreme sea level events.

Projections of changes in the Atlantic Meridional Overturning Circulation (AMOC) from the CMIP5 models do change substantially the picture emerged from the CMIP3 model in the AR4, indicating that it is very likely that the AMOC will weaken in the 21st century as a result of increased GHG concentrations (by 10-30% in the RCP4.5 scenario and 20-40% in the RCP8.5) but it is very unlikely that it will undergo an abrupt transition or collapse for the scenarios considered (WGI Chapter 12).

21.4.1.3. Air Quality

Changes in air pollutants such as near surface ozone and particulate material may have effects on human health, agriculture and natural ecosystems. These changes may depend on changes in emissions or changes in climatic and meteorological conditions affecting transport and removal of the pollutants. Therefore the issues of climate change and air quality are deeply interconnected (Giorgi et al. Meleux 2007).

21.4.1.3.1. Main conclusions from the AR4

In the AR4 it was concluded that background levels of near surface ozone have increase since pre-industrial times because of increased emissions, however future emissions are difficult to predict and this adds a strong element of uncertainty to air quality projections. Taking into consideration changes in emissions and climate over metropolitan areas of the U.S. and England, a few studies indicated a general increase of ozone mainly related to higher temperatures and a decrease in SO2 and particulate material.

21.4.1.3.2. New understanding and emerging knowledge

Since the AR4 the interest in climate-air quality interactions has increased and more studies have become available addressing the issue of the effects of both climate and emission changes on air quality. Most of these studies focused on the continental United States and Europe, and utilized both global and regional climate and air quality models run in off-line or coupled mode. Regional modeling studies over the United States or some of its sub-regions include, for example, those of Hogrefe et al. (2004), Knowlton et al. (2004), Steiner et al. (2006), Dawson et al. (2006), Lin et al. (2008), Weaver et al. (2009), Zhang et al. (2008), while examples of global modeling studies include Murazaki and Hess (2006), Stevenson et al. (2006), Shindell et al. (2006), Doherty et al. (2006). Weaver et al. (2009) provide a synthesis of simulated effects of climate change on ozone concentrations in the U.S. using an ensemble of regional and global climate and air quality models. These studies indicate a predominant increase in near-surface ozone concentrations, particularly in the Eastern U.S. (Figure 21-12) mostly tied to higher temperatures and corresponding biogenic emissions. An even greater increase was found in the frequency and intensity of extreme ozone concentration events, which are the most dangerous for human health.

Examples of regional studies of air quality changes in response to climate change over Europe include Langner et al. (2005), Forkel and Knocke (2006) , Szopa and Hauglustaine (2007), and Meleux et al. (2007), Carvalho et al. (2010), Engartd et al. (2009), Andersson and Engardt (2010), Kruger et al. (2008), Athanassiadou et al. (2010). All these studies indicated the potential of large increases in near surface summer ozone concentrations especially in Central and Southern Europe due to much warmer and drier projected summer seasons (Figure 21-13).

[INSERT FIGURE 21-12 HERE
Figure 21-12: Mean (top panels) and standard deviation (bottom panels) in future-minus-present MDA8 summer ozone concentrations across (left-hand panels) all 7 experiments (5 regional and 2 global) and, for comparison purposes (right-hand panels) not including the WSU experiment (which simulated July only conditions). (From Weaver et al. 2009)]

[INSERT FIGURE 21-13 HERE
Figure 21-13: Difference in average summer daily ozone mean (left panel) and peak (right panel) concentration over Europe due to climate change, A2 scenario. (From Meleux et al. 2007)]

In general, while a consistently predominant increase of ozone concentrations due to climate change was found in these experiments, results were more mixed and regionally/seasonally dependent for other pollutants such as PM, sulfur and nitrogen compounds. It should be mentioned that most studied addressed the issue of climate effects on ozone without changes in anthropogenic emission. However, these are likely to change as well, and thus modulate the climate-related signals.

21.4.1.4. Cryosphere

The cryosphere is one of the most sensitive components of the climate system to global warming, and this response, which has profound implications for changes in sea level rise and atmospheric circulations, is determined by very complex processes, some of which are still poorly understood (e.g. ice flow dynamics).

21.4.1.4.1. Main conclusions from the AR4

Observations up to the AR4 showed that mountain glaciers and snow cover have declined on average in the 20th century in both hemispheres and that decreases in glaciers and ice caps contributed to global sea level rise. Losses from the ice sheets of Greenland and Antarctica were also found to have very likely contributed to sea level rise during 1993-2003. Averaged arctic temperatures increased almost twice the global average rate during the 20th century, illustrating the large sensitivity of the Arctic regions to global warming. Arctic sea ice extent shrunk y 2.7 [2.1 to 3.3]% per decade from 1978 to 2003 and the maximum area covered by seasonally frozen ground decreased by 7% (up to 15% in spring) in the northern hemisphere during the 20th century.

Concerning 21st century projections, under all SRES scenarios the arctic region was projected to warm at a rate much higher than the global average, snow cover and ice caps were projected to contract, thaw depth to increase over most permafrost regions, sea ice to shrink over both the Arctic and Antarctic (with arctic late summer sea ice disappearing almost entirely in the late 21st century for some scenarios). Contraction of the Greenland ice sheet was projected to continue, and to contribute to sea level rise, beyond 2100 and a negative surface mass balance continuing for millennia would eventually lead to virtually complete elimination of the Greenland Ice Sheet and a contribution of sea level rise of up to 7 m. The Antarctic Ice Sheet was projected to remain too cold for widespread surface melting and was expected to gain in mass due to increased precipitation. However, poor understanding of dynamical ice flow processes made many of these estimates quite uncertain.

21.4.1.4.2. New understanding and emerging knowledge

New and improved data have become available since the AR4 to evaluate changes in the cryosphere (WGI Chapter 4), most notably the GRACE satellite ones, which have allowed more accurate assessments of the ice sheet mass balance. These improved observations show that the retreat of Arctic ice in all seasons has continued, at a rate of 4% per decade annually and 12% per decade during the summer. The thickness of arctic ice has also decreased, with a loss of mass of 17% per decade between 1979 and 1999 and another 40% since 1999. Conversely, the total extent of Antarctic ice has increased slightly (1.3% per decade) between 1979 and 2010, with strong regional differences. Retreat of mountain glaciers is widespread, with varying rates across regions. In particular, increasing loss of glacier mass has been observed in recent decades over Central Europe, Alaska, the Canadian Arctic and the Southern Andes. Global glacier mass loss is currently about 1 mm Sea Level Equivalent (SLE) per year, slightly slower in 2001-2005.

Because of better techniques and more data, confidence has increased in the measurements of Greenland and Antarctica ice sheets. These indicate that parts of the Antarctic and Greenland ice sheets have been loosing mass over the last two decades and contribute to global sea level rise. During 1992–2011, Greenland lost on average 120 ± 30 Gt yr-1 (6–7 mm of SLE) and Antarctica lost 75 ± 20 Gt yr-1 (4 mm of SLE). In the GRACE period 2002–2011, the losses were higher, 230 ± 30Gt yr-1 in Greenland and 175 ± 70 Gt yr-1 in Antarctica. These mostly caused by changes in ice flow in Antarctica, and a mix of changes in ice flow and increases in snow/ice melt in Greenland.

New data, both in situ and from satellite confirm a decrease in snow cover extent in most months, particularly in spring (WGI Chapter 4). Trends of snow variations vary considerably across regions, but in general decreased snow is found in relatively warm regios sensitive to spring snow cover and increased snow in very cold regions where precipitation has increased. During the past three decades, significant permafrost degradation occurred. Permafrost temperature has increased (up to 3°C since the late-1970s in some regions of the Arctic and the areal extent of permafrost is declining. The thickness of seasonally frozen ground has decreased in the 20th century across Russia and from 1960 to the present on the Qinghai-Xizang (Tibetan) Plateau. The thaw season has expanded by more than two weeks from 1988 through 2007 across central and eastern Asia.

Twenty first century projections of cryosphere changes are based on the CMIP5 ensemble, which shows long-term reductions in sea ice areal coverage in both hemispheres, greatest in summertime over the Northern Hemisphere (WGI Chapter 12). The CMIP5 models also better capture the rapid decline in summer Arctic sea ice observed during the last decades than CMIP3 models. However, the spread in sea ice projections across models remains high, although most models project nearly ice-free September conditions in the Arctic by 2100 in the RCP8.5 scenario. Future projections of Southern Hemisphere sea ice remain comparatively more uncertain compared to the Northern Hemisphere. The models show no evidence of critical thresholds in the transition from perennial ice-covered to a seasonally ice-free Arctic Ocean beyond which further sea ice loss is unstoppable and irreversible. Projections of decrease in Northern Hemisphere spring snow covered area in the CMIP5 models are fairly coherent (decrease of about 9% in RCP2.6 and 24% RCP8.5 by 2100). Surface permafrost area is projected to decrease between 31% (RCP2.6) to 73% (RCP8.5) by 2100.

21.4.2. Mitigation Research

A complete understanding of the regional context for vulnerability, impacts, and adaptation also includes consideration of both the current state and potential for mitigation of greenhouse gas emissions – either through deployment of energy technologies or management of sinks. A complete understanding of mitigation research is beyond the scope of this chapter, or of Working Group II. Here we focus only on those aspects of mitigation research that are intrinsically linked to, or intersect with climate impacts and the evolution of vulnerability.

21.4.2.1. Projections of Land-Use Change and Biofuels

Land-cover and land-use are related in multiple ways to the regional distribution of vulnerabilities, both because they are intrinsically part of the distribution of natural resources and of goods and services from ecosystems (e.g. Scholes et al 2005, Janetos et al 2005), but also because they are changing rapidly as a consequence of both societal demands for those goods and services, and because of variability in the climate system. While documenting global patterns of land-cover change has been a focus for observational research for many years in particular ecosystem types (e.g. forests in Lepers et al. 2005, Hansen et al.), the projections of land-use and land-cover change have typically either focused on human-driven changes (Rindfuss 2008) or on the sensitivity of ecosystems to climate variability, but rarely both. Land-use and land-cover histories have been harmonized for use in future simulations as part of the RCP process (Hurtt et al 2011).

More recent literature begins to address new aspects of land-use and land-cover change as those processes relate to greenhouse gas mitigation actions. Meinshausen et al (in press), Van Vuuren et al. (2011), Thomson et al. (2010), and Wise et al. (2009) present scenarios of land-use and land-cover change that have focused on how those changes are also consequences of decisions about greenhouse gas mitigation, especially the potential for expansion of purpose-grown bioenergy crops. The extent and rapidity of spread of purpose-grown bioenergy crops in these studies using integrated assessment models is largely a function of economic behavior- specifically, whether a price is associated with terrestrial carbon as well as fossil fuel emissions, or whether a price is only associated with fossil fuel emissions. In some models, (Thomson et al 2010, Wise et al 2009), bioenergy crops are used for electricity generation when coupled with geological capture and sequestration. This is not a general result, however, as all integrated assessment models do not represent that particular combination of technologies. In model results that have large expansions of purpose-grown bioenergy crops, there is also a larger expansion of cropland for food production to satisfy the demand for food from growing human populations. This result is due to the fact that the competition for arable land forces agriculture onto less suitable lands and lowers their per hectare productivity. However, while the interaction between land-use, bioenergy crops, and agricultural productivity is beginning to be investigated, the interaction with the climate system itself is still largely unexplored, so our understanding of these interactions is still in a very preliminary stage. Hibbard et al (2010) present an analysis of the major uncertainties and research gaps in addressing this interaction.

21.4.2.2. Regional Aspects of Evolution of Technologies

The availability of new or more efficient energy technologies both on supply and demand sides lowers the overall cost of achieving any arbitrary concentration or radiative forcing target (Edmonds et al 2007, 2008, Clarke et al 2007). But it is clear that there is great regional variation in the penetration of different technologies for both well-known technologies, and especially for emerging technologies. While models often simulate the spread of technologies on a regional basis simply as a function of economic principles, their actual spread is a function of a combination of economics, politics, institutional issues, the availability of financing, and human capital (Baker et al 2008, Clarke et al 2008). These differences may be described, but they are extraordinarily difficult to predict (Clarke et al 2008). Current models that include either coarse or very detailed descriptions of technologies must be used to generate different scenarios of regional spread of technologies, and therefore their availability (Clarke et al 2007).

21.4.2.3. Socioeconomic and Development Pathways

Predicting socioeconomic and development pathways, and understanding the interactions of mitigation and adaptation capacities that are inherent in them, is not currently possible. However, there are a variety of indices of vulnerability, some of which can be projected forward as scenarios (Malone and Engle 2010, Yohe et al 2007) to understand the degree to which different development pathways may affect societies' underlying vulnerabilities. There are a very large number of possible socioeconomic and development pathways that have been explored in the greenhouse gas mitigation literature, from the SRES (IPCC, 2000b) to the new RCP process (Moss et al. 2010). Assumptions and scenarios of socioeconomic and development pathways are also commonly developed for other scientific and environmental assessments: e.g., the Millennium Ecosystem Assessment (MA), UNEP's GEO process (Rothman et al 2007). AR4 (Yohe et al 2007) showed that there are common determinants of mitigation capacity, sustainable development, and resilience/adaptive capacity.

But there has been very little research on scenarios that incorporate or investigate the joint aspects of mitigation and adaptation capacity. While Moss et al (2010) have outlined one such process, the development of adaptation/resilience scenarios has lagged the development of mitigation scenarios. Van Vuuren et al (2012) and Adger et al (2011) explore the relationships between scenarios in these quite different domains, and present a framework for analysis of joint scenarios. Hallegatte et al. (2011) also offer an alternative framework for global scenario construction serving both mitigation and IAV needs.

21.4.3. Approaches to Deriving Robust Information on Regional Change

Obtaining robust predictions, i.e. at least a clear understanding of the direction of change preferably with a level of quantification, requires combining the projections with detailed analysis and understanding of the drivers of the changes. The most successful example of this is the application of the attribution of observed global and regional temperature changes using global models incorporating known natural and anthropogenic climate forcing factors

(AR4 WG1). The global model's ability to reproduce the observed variations in temperature, the quantification of the influence of the different forcings factors and how well these influences are captured in the models provide for:

- Confidence that models capture correctly the physical processes driving the changes and thus in their ability to project future changes;
- A method of quantifying the range of sensitivities of the climate system to the different forcings factors and thus how it is likely to respond to scenarios of changes in these forcing factors.

In this situation, a robust message was derived due to having a clear understanding of the drivers of observed changes and all models reproducing these along with the direction and, to a reasonable degree of accuracy, the magnitude of the change.

Through a careful analysis of the drivers of projected changes, similar robust messages can be derived for precipitation change. Rowell and Jones (2006) performed a detailed analysis of the drivers of projected European drying in summer and concluded this signal to be robust as the dominant processes were driven by warming. In a similar analysis Kendon et al. (2010) concluded that the signal of increased daily precipitation in Europe in winter was also robust.

However, in other situations, future projections may go in opposite directions to each other with neither possibility able to be excluded on the basis of our physical understanding of the drivers of these changes. For example, McSweeney et al., (2011) found that in an ensemble of GCM projections over south-east Asia, all models simulated the important monsoon processes and rainfall well but projected both positive and negative changes in monsoon precipitation and significantly different patterns of change. In this case no information on observed trends or more detailed process understanding was available but there has been little effort to analyse trends and projected changes in south-east Asia and thus the current issue of contradictory projections could be clarified with some targeted research.

21.5. Regional Distributions of Key Issues

This section highlights regional distributions of key issues and briefly considers related methodological issues. It focuses on indices, maps and hotspots studies to assess what the literature says about the advantages or disadvantages of analysing information about vulnerability, impacts and adaptation at a global or large-region scale. The value of taking a regional and global approach to vulnerability, impacts and adaptation is the ability to compare and contrast sub-regions. Regionally distributed impacts information can for example be assessed in conjunction with examinations of regional political economies to provide a context for understanding implications of impacts.

Determining what belongs to a region or sub-region is addressed in 21.2, but deserves mention in the context of how to represent causal links of a geographical nature across regions and within them. Although climate change will affect different places in different ways, there will be spillover effects from one location to the next (Foresight International Dimensions of Climate Change, 2011). For instance, a spillover effect occurs when there is a significant drought in a food-exporting country leading to food scarcity or insecurity in other countries (Sasson, 2012). Understanding vulnerability, impacts and adaptation (adaptive capacity) on a global level has the advantage of categorising population groups, ecosystems and locations that will be affected the most severely, to prioritise funding and identify cross-regional learning opportunities. The disadvantage is that many of the approaches to represent the information are unable to reflect the complexities of the situation (Hinkel 2011). Furthermore, drivers of vulnerability, enabling environments for adaptation and the consequences of impacts are differentiated in ways that cannot easily be compared. Thus the comparability of global information on vulnerability, impacts and adaptation is limited from certain perspectives (more refs).

Identifying appropriate variables to measure vulnerability and adaptive capacity/adaptation requires a profound understanding of what these variables are (Malone and Engle 2011, Hinkel 2011, Luers et al 2003). Although extensive research has been done to identify the drivers of vulnerability and adaptive capacity, primarily through case studies, there are many uncertainties regarding how to characterise the nature of these drivers and consequently how to project their influence on vulnerability and adaptive capacity in the future.

Maps have been used to show risk, hazards and vulnerability (Edwards et al 2007, Arnold et al 2006, Dilley et al 2005). Mapping vulnerability is more than just overlaying impact information with demographic information because there has to be some correlation between the impacts and the indicators that are selected to represent vulnerability. Maps continue to be used, even though they often lead to more generating more questions than answers (Preston et al 2007). Hotspots or maps of vulnerability, impacts and adaptive capacity are popular because they facilitate the job of prioritising funding and project attention (Ericksen et al 2011, Klein 2009).

21.5.1. Vulnerabilities

21.5.1.1. Methodological Issues

The comparison of vulnerability across regions requires require some common baseline from which to judge relative levels of vulnerability – a type of measurement. Measuring vulnerability to climate change is typically done through assessments, which can be top-down, bottom-up or a combination (TERI et al 2012). Qualitative and quantitative studies are used to identify why people are vulnerable and how, and are typically the basis for determining strategies for reducing vulnerability and adapting to climate change. Bottom-up assessments mostly focus on current climate variability, since future vulnerability is also uncertain. It has been discovered that vulnerability assessments can also be used to compare different groups of people, depending on variables such as their age, gender, caste, state of health, livelihood, physical location, political affiliation, wealth, among many other things (Wisner et al 2005).

Several attempts at developing vulnerability indicators and indices have been made (Luers et al, 2003; Downing *et al.*, 2001, Moss *et al.*, 1999, Villa and McLeod, 2002, Hughes and Brundritt, 1992, Gornitz *et al.*, 1994, Shaw *et al.*, 1998, Lawrence *et al.*, 2003, Atkins *et al.*, 2000). Representation of vulnerability on a map or through an index is the most common way to show global vulnerability information and requires quantification of selected variables in order to measure them against a selected baseline, even though quantification of some qualitative information may not be possible (Luers et al 2003, Hinkel, 2011, Edwards et al, 2007). Maps of vulnerabilities where hazards or projected climate change impacts are overlain with population density suggests that everyone has an equal probability of being affected by a hazard or by climate change impacts, ie. that everyone is equally at risk. There is high confidence that vulnerability is differentiated according to factors such as gender, age, livelihood, access to social networks, etc. (REFs) and therefore choice of indicators of or proxies for vulnerability will determine what is actually shown. One approach that is used to create regional comparisons is an *index* approach that measures different variables to create indicators of vulnerability. The index is the composite of several normalised indicators (Adger et al 2004, Rygel et al 2006). The approach has been critiqued extensively (Fuessel 2010). Although a number of vulnerability indicator methodologies have been developed, the majority have been critiqued and no commonly accepted approach exists. The Luers et al (2003) approach has been the most cited, but critiqued because it requires indicators and the relative importance of the selected information for determining vulnerability to be held static, assuming no fluctuation over time. Given that variables such as health or access to agricultural extension services that may play an important role in determining vulnerability to climate change at a given time will also change over time, this approach can result in misinformed policy and funding decisions.

The selection of indicators has been addressed extensively in the literature (Malone and Engle, 2011; Brooks et al, 2005) and one stand-out message is that the information selected to represent vulnerability is highly subjective. Lack of full understanding of what drives vulnerability means that indicators can give misleading or incorrect information about vulnerability (Böhringer and Jochem, 2007). Luers et al 2003 and others suggest that even at a local level, selection of variables to measure as indicators will influence the results, and Hinkel (2011) concludes that a quantitative global-level vulnerability assessment is not possible.

Luers et al (2003) propose the idea of ex-post measure of vulnerability, using the number of people killed in a storm as an indicator that they were vulnerable. A deductive analysis of the situation would suggest that they were killed because (a) they were exposed to the storm, (b) they were sensitive to the storm, (c) they had low capacity to escape the storm or (d) the storm had a very high impact. However, a low impact storm could also result in deaths if the people were especially sensitive or exposed. Their deaths could also simply be explained by being in the wrong place at the wrong time, which suggests that ex-post analysis only can indicate the state of vulnerability of the people killed at the moment they were killed, and not anything else. Conversely, an ex-ante analysis of vulnerability to a storm might suggest that old people, people who are unlikely to evacuate their houses because they do not want to risk losing their assets (such as livestock) or people who have a lack of knowledge of where to go and what to do in an emergency, would be the most sensitive and exposed. But the outcome does not necessarily lead to death, since they could also be rescued, their area could be unaffected by the storm, or they could survive anyway. In other words, identifying a single characteristic or even several may not give a sufficient picture of vulnerability for decision making, even on a local level.

Vulnerability indicators developed to date have been unable to reflect the dynamic nature of the various variables used as indicators. This is illustrated in the case of the (in)ability to characterise how the selected indicators contribute to determining vulnerability over time. Importantly, the relative importance of the indicator may change from season-to-season (eg, access to irrigation water) or gradually or rapidly become obsolete. Hinkel's (2011) review of literature on vulnerability indicators suggests that vulnerability has been confused as a proxy for unsustainable or insufficient development, which means that simple measurements are seen as sufficient to tell a story about vulnerability. Hinkel (2011) suggests that the simplification of information to create vulnerability indicators is what makes the vulnerability indicators useless.

There is no question that confusion about the definition of vulnerability, risk and hazard influence the messages that result from mapping or index exercises. Guidelines' explanation of the purpose of measuring vulnerability provides conflicting messages, with UNEP's vulnerability map handbook suggesting that maps are able to indicate 'the precise location of sites where people, the natural environment or property are at risk due to a potentially catastrophic event that could result in death, injury, pollution or other destruction' (Edwards et al 2007: 3), which elsewhere would be defined as a 'risk map', 'hazard map' or 'exposure map'.

21.5.1.2 Regional Distribution

[Table 21-3 PLACEHOLDER This marks a placeholder for a comparative table that will summarise vulnerability findings in key systems according to the first half of WG2's contribution in the different regions as laid out in the second half of WG2's contribution. The purpose of this table is to inform those who are interested in regions of vulnerability issues that appear in the systems chapters, and those who are interested in systems of vulnerability issues that appear in the regional chapters.]

21.5.2. Impacts

21.5.2.1. Methodological Issues

Global models of impacts have been the starting point for much policy work since the FAR (1990). Integrated assessment models have grown in importance, since they couple multiple layers of information to provide more policy-relevant information.

A review of contributions to the climate-economics literature assesses 30 existing integrated assessment models (IAMs), focusing on climate-economics models. They found that the results of such [the best-known climate-economics models] are 'only as good as their underlying structures and parameter values' (Stanton et al 2009). The results of IAMs are driven by 'conjectures and assumptions that do not rest on empirical data and often cannot be tested against data until after the fact' (Stanton et al 2009). Accordingly, results depend on which theories about future economic growth and technological change were incorporated into the model design and on ethical and political judgments.

Shortcoming of global modeling efforts vis-à-vis policy utility include:

- Inadequate and incomplete understanding of the systems being modeled and a concomitant lack of attention to model verification;

- Failure to be sufficiently specific about the objectives of the modeling projects;
- Failure to carefully examine the implications of uncertainty in input variables and model time constants;
- Inability to deal with the stochastic elements in the systems being modeled; and
- Difficulties arising from the ideological perspectives of the analyst.

Other limitations include:

- The systems modelled are large, complex, and chaotic;
- The complexity of natural and social systems cannot be captured by IAMs;
- The full consequences of policies considered will not be known for decades or centuries;
- Scientific knowledge is incomplete or absent in many areas; and
- Values of human, animal, and plant life, health, and diversity are difficult to quantify.

IAMs are limited in scope does not dismiss their usefulness. IAMs are intended to be tools for furthering our understanding of the climate change problem and not predictive models of what might take place. As such, they can provide insights into the climate change problem that are not available through other analytical and decision-making tools.[8]

[FOOTNOTE 8: http://sedac.ciesin.columbia.edu/mva/iamcc.tg/mva-questions.html]

21.5.2.2. Regional Issues

[Table 21-4 PLACEHOLDER This marks a placeholder for a comparative table that will summarise impacts findings in key systems according to the first half of WG2's contribution in the different regions as laid out in the second half of WG2's contribution.]

21.5.3. Adaptation Approaches

21.5.3.1. Methodological Issues

Adaptation is considered to be tightly linked with development (Adger et al 2003b, Schipper 2007) and a significant portion of adaptation approaches emerge from activities in developing countries. The metrics of adaptation is a topic of considerable interest for the purpose of funding prioritisation, monitoring progress in adjusting to climate change and identifying suitable adaptation options (IGES 2008).

Adaptation assessment as a process is described more extensively in chapters (xxx) and this section addresses the usefulness of regional and global assessments. What is typically assessed is either adaptive capacity (Yohe and Tol 2002), which is based on some variables that are often transformed into indicators, success of implementation of adaptation projects (often also based on a set of indicators) or 'functions' that countries should follow to attain resilience (WRI 2009).

As a way of understanding adaptive capacity further, numerous types of indicator systems have been developed. These are used both to measure adaptive capacity as well as to identify entry points for enhancing it (Adger and Vincent, 2005; Eriksen and Kelly, 2007; Downing et al, 2001; Brooks et al 2005; Lioubimtseva and Henebry, 2009; Swanson et al., 2007). For example, the Global Adaptation Index, developed by the Global Adaptation Alliance (GAIN, date?), uses a national approach to assess vulnerability to climate change and other global challenges and compare this with a country's 'Readiness to improve resilience' (GAIN, date) for the purpose of assisting public and private sectors to prioritise financial investments in adaptation activities.

Indicators can be a useful starting point for a discussion on what qualifies as an appropriate proxy for capacity, in order to determine what sort of factors act as barriers and drivers. When rooted in the poverty and livelihoods discourse on vulnerability (Chambers, 1989; Swift, 1989), proxies for capacity look very similar to indicators of development, despite the significant argument about the causal structure of vulnerability, which underscores that vulnerability is not the same as poverty (Chambers, 1989; Ribot, 1996). Resources may be for enhancing 'the capacity and endurance of the affected people to cope with adversities' (Ahmed and Ahmad 2000: 100), but equating vulnerability with poverty creates a false association between lack of development and lack of capacity (Magnan, 2010).

21.5.3.2. Regional Issues

[Table 21-5 PLACEHOLDER This marks a placeholder for a comparative table that will summarise adaptation issues in key systems according to the first half of WG2's contribution in the different regions as laid out in the second half of WG2's contribution.]

21.5.4. Sectoral Issues

[This section will draw on issues described by the sectoral FODs and will therefore be stronger in the SOD. The issues here will focus on sectors identified in the AR4 SPM rather than systems that are how the chapters in the AR5 WG2 have been divided]

The agriculture sector has received the largest share of attention and research with respect to regional comparisons of climate change impacts and vulnerability because of the global importance of food production. The impacts of climate change on agriculture is particularly important to Africa, where a large portion of the region's population is composed of small-holder and subsistence farmers [Chapter 22]. This is also the case in Asia, but the region also has significant sectors that are less sensitive to climate change.

Agriculture has a strong regional dimension as a result of global food trade.

Threats to water quantity, quality and availability at key times is a recurring issue across regions. Too little water is just as relevant as too much water, but has different implications.

[Table 21-6 PLACEHOLDER This marks a placeholder for a comparative table that will summarise sectoral issues in key systems according to the first half of WG2's contribution in the different regions as laid out in the second half of WG2's contribution.]

[This section will draw on issues described by the FODs and will therefore be stronger in the SOD; it will also be informed by what is presented in the Tables in the sections above.]

Hotspots is an approach that has been used to indicate locations that stand out in terms of impacts, vulnerability or adaptive capacity (or all three). The approach exists in other fields and the meaning and use of the term hotspots differs (see Box 21-4). The term typically relates to a geographical location, which emerges as a concern when multiple layers of information are compiled. For example, the Climate Change Agriculture and Food Security (CCAFS) mapped hotspots of food insecurity and climate change in the tropics (Ericksen et al, 2011). Other studies look at how climate change can influence disease risk (de Wet et al 2001), extinctions of endemic species (Malcolm et al 2005), and disaster risk (Dilley 2006). The purpose of the hotspots is to set priorities for policy action and for further research (Dilley 2006, Ericksen et al 2011).

_____ START BOX 21-4 HERE _____

Box 21-4. Hotspots

[Placeholder to be developed subject to materials from FOD in other WGII chapters]

Hotspots is a concept used in numerous fields to describe locations that stand out as important for the analytical lens that is being applied. The purpose of doing hotspot analysis varies across different fields, but they are typically the outcome of the combination of different sets of variables with a geographical reference. The use of hotspots differs according to multiple factors, including the scale of analysis (from specific houses to entire ecosystems), the number of variables examined (two or more), whether the information refers to measured or projected hotspots. Hotspots can contrast with 'cool spots', where the inverse situation can be found, and can be ranked when they are derived from numerical values (eg. number of crimes committed). Hotspots are another way of comparing regions, and the subjective nature of ranking locations as more urgent than others is controversial and can be considered politically-motivated (Klein 2009).

Climate Change: A climate change hotspot can describe (a) a region for which potential climate change impacts on the environment or different activity sectors can be particularly pronounced or (b) a region whose climate is especially responsive to global change (Giorgi 2006). Others have defined climate change hotspots as locations where impacts of climate change are 'well pronounced and well documented' (UCS 2011).

Biodiversity and Conservation: A biodiversity hotspot is a recognised concept and unit of analysis for guiding policy and investment decisions, developed by Meyers (1988). It is a region that is biologically diverse and typically under some sort of threat from human activity, climate change, or other drivers.

Health and Disease: Hotspots of disease can describe incidence rates, death rates, areas where certain viruses are likely to emerge, among other things. They can be coupled to climate change, biodiversity change, population growth, human-animal proximity, or to other drivers. A study on emerging infectious diseases (EIDs) identified hotspots as regions where new EIDs are likely to originate, in order to guide decisions makers where to allocate global resources to pre-empt, or combat, the first stages of disease emergence (Jones et al 2008).

Crime and Conflict: Crime hotspots are of interest on a local level, and offer a way for police to identify concentrations of crime and thereby determine areas that require priority attention (Eck et al 2005). Crime hotspots are defined as an area with greater than average criminal or disorder events, or an area where people have a higher than average risk of victimisation (Eck et al 2005).

Conflict hotspots describe areas of where violent conflict occurs or has a higher chance of occurring (Braithwaite, 2010). A reverse approach can be found in the Global Peace Index developed by the Institute of Economics and Peace (IEP, 2011).

Disasters: Disasters hotspots are identified as geographic areas that are most vulnerable to hazards (Dilley et al 2006). The purpose of disasters hotspots is to encourage development agencies and policy makers to incorporate disaster risk management into investment plans and decisions (Arnold et al 2005).

Food production, Food security: Areas of food production that are affected by pressures such as urbanisation, environmental degradation, water scarcity or climate change can be identified as hotspots of food insecurity, such as by CGIAR CCAFS (Ericksen et al 2011). Similarly, adverse implications of agriculture on environment have been described as 'agri-environmental hotspots'. FAO (2010) defines agri-environmental hotspots as 'locations where human activities are detrimental to the sustainability of an ecosystem or the human activities depending on it'. The purpose of identifying such hotspots is because 'they may gradually evolve into extremely tense socio-economic situations associated with a severe degradation of the natural resources base and food security' (FAO 2010).

_____ END BOX 21-4 HERE _____

The identification of hotspots raises important methodological issues discussed in section 21.1.2 with regard to the limitation of indicators to give an illustration that integrates impacts with qualitative dimensions of vulnerability. Certain areas are considered hotspots because of their regional or global importance. These can be defined by population size and growth rate, contributions to regional or global economies, productive significance (eg food production) as well as by disaster frequency and magnitude, and projected climate change impacts. Variables identified to represent these issues can be controversial, and relationships between variables may not always be fully understood. The CCAFS hotspot map uses stunted growth as a proxy for food insecurity (Ericksen et al 2011), but other variables could also have been selected. Scale matters in representing hotspots and will look differently on a global scale than on a finer scale (Arnold et al 2006).

21.6. Cross-Regional Phenomena

Thus far, this chapter has covered climate change-related issues that have a regional expression in one part of the world or another. In principle, these issues can be studied and described, *in situ*, in the regions in which they occur. However, there is a separate class of issues that transcends regional boundaries and demands a different treatment. In order to understand such cross-regional phenomena, knowledge is required of critical but geographically remote associations and of dynamic cross-boundary flows. The following sections consider some examples of these phenomena, focusing on trade and financial flows and migration. Though these issues are treated in more detail in Part A of this report, they are restated here in Part B to stress the importance of a global perspective in appreciating climate change challenges and potential solutions at the regional scale.

21.6.1. Trade and Financial Flows

Global trade and international financial transactions are the motors of modern global economic activity, and are inextricably linked to climate change through a number of pathways: (i) as a direct or indirect cause of anthropogenic emissions, (ii) as a predisposing factor for regional vulnerability to the impacts of climate change, (iii) through their sensitivity to climate trends and extreme climate events, and (iv) as an instrument for implementing mitigation and adaptation policies.

21.6.1.1. International Trade and Emissions

The contemporary world is highly dependent on trading relationships between countries in the import and export of raw materials, food and fibre commodities and manufactured goods. A rapidly growing world population and expanded economic activity in many developing countries during the past two decades has fuelled increasing demand for imports. The engines of manufacturing are now located in developing countries with a young and relatively cheap workforce, with only high value products retaining competitiveness in the developed world. Even during a period of general recession since 2008, economic development in many emerging, export-led economies (e.g. China, India, Ghana and Brazil) succeeded in bucking the global trend (World Bank, 2011).

Bulk transport of these products, whether by air, sea or over land, is now a non-trivial contributor to emissions of greenhouse gases and aerosols. Furthermore, the relocation of manufacturing has transferred net emissions via international trade from developed to developing countries (see Figure 21-14), and most developed countries have increased their consumption-based emissions faster than their domestic (territorial) emissions (Peters *et al.*, 2011). This regional transfer of emissions is commonly referred to in climate policy negotiations as "carbon leakage" (Barker et al., 2007), though only a very small portion of this can be attributed to climate policy ("strong carbon leakage"), a substantial majority being due to the effect of nonclimate policies on international trade ("weak carbon leakage" – Peters, 2010). A particular example of strong carbon leakage concerns the conversion of land use from the production of food to bioenergy crops. These crops sequester carbon otherwise extracted from the ground as fossil fuels, but in the process displace demand for food production to land in other regions, often inducing land clearance and hence an increase in emissions (Searchinger, 2008), though the empirical basis for this latter assertion is disputed (see Kline and Dale, 2008).

[INSERT FIGURE 21-14 HERE
Figure 21-14: Growth rates from 1990-2008 of international trade, its embodied CO_2 emissions and net emissions transfers from Annex B and non-Annex B countries compared to other global macrovariables, all indexed to 1990 (Peters et al., 2011).]

21.6.1.2. Trade and Financial Flows as Factors Influencing Vulnerability

The increasingly international nature of trade and financial flows (commonly referred to as globalisation), while offering potential benefits for economic development and competitiveness in developing countries, also presents high exposure to climate-related risks for some of the populations already most vulnerable to climate change. Examples of these risks, explored further in Chapters 7-9, 12 and 13 of Part A, include:

- Severe impacts of food price spikes in many developing countries (including food riots and increased incidence of child malnutrition) such as occurred in 2008 following shortfalls in staple cereals, due to a coincidence of regional weather extremes (e.g. drought) in producer countries, the reallocation of food crops by some major exporters for use as biofuels (an outcome of climate policy – see previous section) and market speculation (Ziervogel and Ericksen, 2010). Prices subsequently fell back as the world economy went into recession, but spiked again in early 2011for many of the same reasons (Trostle et al. 2011), with some commentators predicting a period of rising and volatile prices due to increasing demand and competition from biofuels (Godfray et al. 2010).
- A growing dependence of the rural poor on supplementary income from seasonal urban employment by family members and/or on international financial remittances from migrant workers (Davies *et al.*, 2009). These workers are commonly the first to lose their jobs in times of economic recession, which automatically decreases the resilience of recipient communities in the event of adverse climate conditions.On the other hand, schemes to provide more effective communication with the diaspora in times of severe weather and other extreme events can provide rapid access to resources to aid recovery and reduce vulnerability (Downing, 2012).
- Some aspects of international disaster relief, especially the provision of emergency food aid over protracted periods, has been cited as an impediment to enhancing adaptive capacity to cope with climate-related hazards in many developing countries (Schipper and Pelling, 2006). Here, international intervention, while well-intentioned to relieve short-term stress, may actually be counter-productive in regard to the building of long-term resilience.

21.6.1.3. Sensitivity of International Trade to Climate

Climate trends and extreme climate events can have significant implications for regional resource exploitation and international trade flows. The clearest example of a major prospective impact of climate change concerns the opening of Arctic shipping routes as well as exploitation of mineral resources in the exclusive economic zones (EEZs) of Canada, Greenland, Russia and the USA (and see Chapter 28). Recent projections suggest that the Northern Sea Route, Arctic Bridge, and North Pole routes could become fully accessible from July-September by 2045-2059, representing significant distance savings for trans-continental shipping currently using routes via the Panama and Suez Canals (Stephenson *et al.*, 2011). Indeed, in 2009 two cargo vessels – the Beluga Fraternity and Beluga Foresight – became the first to successfully traverse the Northeast Passage from South Korea to the Netherlands, a reduction of 5,500 km and 10 days compared to their traditional 20,000 km route via the Suez Canal, translating into an estimated saving of some $300,000 per ship (Smith, 2009). On the other hand, winter transportation routes on frozen ground, which are heavily relied upon for supplying remote communities and for activities such as forestry, are projected to decline in many regions (Figure 21-15).

[INSERT FIGURE 21-15 HERE
Figure 21-15: (To be reworked) Projected change (a) in accessibility of maritime and land-based transportation by mid-century (2045-2059 relative to 2000-2014) using the Arctic Transport Accessibility Model and CCSM3 climate and sea ice estimates assuming an SRES A1B scenario. Green areas denote new maritime access to Type A vessels (light icebreaker); white areas remain inaccessible. Red delimits areas of lost winter road potential for ground vehicles exceeding 2 metric tonnes (Stephenson et al., 2011). Route (b) of the Northwest Passage and Northern Sea Route (right), which is part of the Northeast Passage (Government Office for Science, 2011).]

A second illustration of how the risk of adverse climate changes may have contributed to anticipatory adaptive actions affecting countries in other regions of the world and potentially influencing commodity markets, relates to the purchase or renting of large tracts of productive land in parts of Africa, Latin America, Central Asia and

Southeast Asia by countries in Europe, Africa, the Gulf and South and East Asia (De Schutter, 2009; Cotula et al., 2011; Zoomers, 2011). While there is clearly a profit motive in many of these purchases (i.e., cheap and fertile land and the opportunity to cultivate high value food or biofuel crops), there is also a concern that domestic agricultural production in some countries will be unable to keep pace with rapid growth in domestic demand and changing dietary preferences, especially in agricultural regions affected by frequent shortfalls due to droughts, floods and cyclones (Cotula et al., 2011), or threatened by sea-level rise (Zoomers, 2011). Land acquisition on such a large scale raises a number of ethical issues relating to local access to food and the appropriate and sustainable management of the land (Deininger and Byerlee, 2012). These issues have led the UN Special Rapporteur on the right to food to recommend a list of eleven principles for ensuring informed participation of local communities, adequate benefit sharing and the respect of human rights (De Schutter, 2009).

Extreme climate phenomena that may be harbingers of similar and more frequent events in a warmer world, already exact devastating consequences in some regions that extend well beyond country boundaries. A recent event that disrupted international trade and commodity flows was the severe 2010/2011 flooding in eastern Australia (Giles, 2012; Queensland Floods Commission of Inquiry, 2012; and see Chapter 25), which combined with damaging cyclones in Queensland and Western Australia curtailed numerous mining operations and damaged transportation networks, leading to a fall in coal exports (primarily to Asia) of about 25% (Financial Times, 2011) and a sharp rise in the monthly price of both thermal coal and coking coal between November 2010 and January 2011 (Index Mundi, 2012). The severe weather was the primary factor contributing to a fall in Australian GDP of 1.2% during January-March 2011 compared with a rise of 0.7% in the preceding three-month period (Australian Bureau of Statistics, 2011). Other examples of how extreme climate events can affect international trade are reported by Oh and Reuveny (2010) and Handmer et al. (2012).

21.6.1.4. International Financial Mechanisms as Instruments of Regional Climate Policy

International policies to curb climate change and to adapt to its impacts, are increasingly looking to cross-border financial instruments to encourage action (and see Chapter 16). The European Union Emissions Trading System (EU ETS) is the first and largest international scheme for the trading of greenhouse gas emission allowances, covering some 11,000 power stations and industrial plants in 30 countries and accounting for almost half of the EU's CO_2 emissions and 40% of its total greenhouse gas emissions (European Commission, 2011). The Clean Development Mechanism (CDM) allows industrialised countries (Annex B Parties, cf. Section 2.1.1) to invest in emission-reduction projects in developing countries, which earn certified emission reduction (CER) credits, each equivalent to one tonne of CO_2. These CERs can be traded and sold to meet part of the emission reduction targets of the Annex B Parties under the Kyoto Protocol. Proceeds from the CDM (via a 2% levy on CERs) are being used to fund adaptation under the newly established Green Climate Fund (Green Climate Fund, 2011).

21.6.2. Human Migration

There has been considerable debate in recent years around the postulate that anthropogenic climate change and environmental degradation could lead to mass migration (Perch-Nielsen *et al.*, 2008; Feng et al., 2008; Warner, 2010; Government Office for Science, 2011). Four possible pathways through which climate change could affect migration are suggested by (Martin, 2009):

1) Intensification of natural disasters
2) Increased warming and drought that affects agricultural production and access to clean water
3) Sea-level rise, which makes coastal areas and some island states increasingly uninhabitable
4) Competition over natural resources, leading to conflict and displacement of inhabitants.

Abundant historical evidence exists to suggest that changes in climatic conditions have been a contributory factor in migration, including large population displacements in the wake of severe events such as Hurricane Katrina in New Orleans, Louisiana in 2005 (Cutter et al., 2012), Hurricane Mitch in Central America in 1998, the 1930s Dust Bowl in south-western USA and the northern Ethiopian famines of the 1980s (McLeman and Smit, 2006).

The spatial dimension of climate-related migration is most commonly internal to nations (e.g. from affected regions to safer zones – Naik, 2009). In this context is also worth pointing out that internal migration for other (predominantly economic) reasons may actually expose populations to increased climate risk. For instance, there are large cities in developing countries in low elevation coastal zones that are vulnerable to sea level rise. Increased migration to these cities could exacerbate the problems with the migrants themselves being especially vulnerable (Nordås and Gleditsch, 2007; UNFPA, 2007).

Migration can also be international, though this is less common in response to extreme weather events, and where it does happen it usually occurs along well established routes. For example, emigration following Hurricane Mitch tripled from Honduras and increased from Nicaragua by 40%, mainly to the southern States of the US – already a traditional destination for migrants, and was aided by a relaxation of temporary residency requirements by the United States (Naik, 2009).

The causal chains and links between climate change and migration are complex and can be difficult to demonstrate (e.g., Perch-Nielsen *et al.*, 2008; Piguet, 2010; Tänzler *et al.*, 2010), though useful insights can be gained from studying past abandonment of settlements (McLeman, 2011). Thus projecting future climate-related migration remains a challenging research topic (Feng et al., 2008). There are also psychological, symbolic, cultural and emotional aspects to place attachment, which are well documented from other non-climate causes of forced migration, and are also applicable to cases of managed coastal retreat due to sea-level rise (e.g. Agyeman, 2009). Furthermore, forced migration appears to be an emerging issue requiring more scrutiny by governments in organising development co-operation, and to be factored into international policy making as well as international refugee policies. For example, it has been suggested that the National Adaptation Plans of Action (NAPAs) under the UNFCCC, by ignoring transboundary issues (such as water scarcity), and propounding nationally-orientated adaptation actions (e.g. upstream river management, to the detriment of downstream users in neighbouring countries), could potentially be a trigger for conflict, with its inevitable human consequences. Moreover, currently there is no category in the United Nations High Commission for Refugees classification system for environmental refugees, but it is possible that this group of refugees will increase in the future and their needs and rights will need to be taken into consideration (Brown, 2008). However, migration should not always be regarded as a problem; in certain circumstances where it contributes to adaptation (e.g. through remittances) it can be part of the solution (Laczko and Aghazarm, 2009). Aspects of migration are treated at length in Chapters 8, 9, 12 and 13 of Part A.

21.6.3. Migration of Natural Ecosystems

One of the more obvious consequences of climate change, is the displacement of biogeographical zones and the natural migration of species (see Chapters 4 and 6). General warming of the climate can be expected to result in migration of ecosystems towards higher latitudes and upward into higher elevations. Species shifts are already occurring in response to recent climate changes in many parts of the world (Rosenzweig *et al.*, 2008), with average poleward shifts in species' range boundaries of 6 km per decade being reported (Parmesan *et al.*, 2011).

Study of the estimated shifts of climatic zones alone can provide insights into the types of climatic regimes to anticipate under projected future anthropogenic climate change. By grouping different combinations and levels of climatic variables, it is possible not only to track the shifts in the zones in which they occur, but also to identify newly emerging combinations of conditions not found at the present day (novel climates) as well as combinations that may not survive global climate change (disappearing climates – Williams *et al.*, 2007). These analyses can help define what types of climatic niches may be available in the future and where they will be located. Such a spatial analogue approach (cf. Carter *et al.*, 2007) can delimit those regions that might currently or potentially (in the future) be susceptible to invasion by undesirable aquatic (e.g., EPA, 2008) or terrestrial (e.g., Mainka and Howard, 2010) alien species or alternatively might be candidates for targetting translocation (assisted colonisation) of species endangered in their native habitats (e.g., Brooker *et al.*, 2011; Thomas, 2011). However, there are many questions about the viability of such actions, including genetic implications (e.g., Weeks *et al.*, 2011), inadvertent transport of pests or pathogens with the introduced stock (e.g., Brooker *et al.*, 2011) and risk of invasiveness (e.g., Mueller and Hellmann, 2008).

The ability of species to migrate with climate change must next be judged, in the first instance, against the rate at which the climatic zones shift over space (e.g., Loarie *et al.*, 2009 – Figure 21-16). For projecting potential future species shifts, this is the most straightforward part of the calculation. In contrast, the ecological capacity of species to migrate is a highly complex function of factors, including their ability to:

- Reproduce, propagate or disperse
- Compete for resources
- Adapt to different soils, terrain, water quality and daylength
- Overcome physical barriers (e.g. mountains, water/land obstacles)
- Contend with obstacles imposed by human activity (e.g. land use, pollution or dams).

[INSERT FIGURE 21-16 HERE
Figure 21-16: The velocity of climate change based on the average of 16 global climate models for an A1B emissions scenario and temporal gradients computed for 2050-2100. (Loarie et al., 2009).]

Conservation policy under a changing climate is largely a matter of promoting the natural adaptation of ecosystems, if this is even feasible for many species given the rapidity of projected climate change. Studies stress the risks of potential mismatching in responses of co-dependent species to climate change (e.g. Schweiger et al., 2011) as well as the importance of maintaining species diversity as insurance for the provision of basic ecosystem services (e.g. Traill et al., 2010; Isbell et al., 2011). Four priorities have been identified for conservation stakeholders to apply to climate change planning and adaptation (Heller and Zavaleta, 2009): (i) regional institutional coordination for reserve planning and management and to improve landscape connectivity; (ii) a broadening of spatial and temporal perspectives in management activities and practice, and actions to enhance system resilience; (iii) mainstreaming of climate change into all conservation planning and actions; and (iv) holistic treatment of multiple threats and global change drivers, also accounting for human communities and cultures. The regional aspects of conservation planning transcend political boundaries, again arguing for a regional (rather than exclusively national) approach to adaptation policy. This issue is elaborated in Chapters 4 and 14.

21.7. Knowledge Gaps and Research Needs

[forthcoming]

Frequently Asked Questions

[forthcoming]

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Table 21-1: Selected examples of regional treatment in previous IPCC Assessment Reports and Special Reports (SR). Major assessments are subdivided by the three Working Group reports, each described by generic titles.

IPCC report [references]	**Year**	**Treatment of regions**
First Assessment Report (FAR) [1, 2, 3]	1990	*Climate*: Climate projections for 2030 in 5 sub-continental regions; Observations averaged for northern/southern hemisphere, by selected regions and by 20° latitude x60° longitude grid boxes
		Impacts: Agriculture by continent (7 regions); Ecosystem impacts for 4 biomes; water resources for case study regions; Oceans and Coastal Zones treated separately
		Responses: Emissions scenarios by 5 economic groupings; Energy and Industry by 9 regions; Coastal Zone and Wetlands by 20 world regions
Supplements to FAR [4, 5]	1992	*Climate*: IS92 emissions scenarios by 7 world regions
		Impacts: Agriculture by continent (6 regions); Ocean Ecology by 3 latitude zones; Questionnaire to governments on current activities on impacts by 6 WMO regions
SR*: Climate Change 1994* [6]	1994	Evaluation of IS92 emissions scenarios by 4 world regions: OECD, USSR/E. Europe, China/Centrally Planned Asia and Other.
Second Assessment Report (SAR) [7, 8, 9]	1995	*Climate*: Gridded proportional circle maps for observed climate trends (5° latitude/ longitude); climate projections for 7 sub-continental regions
		Impacts, Adaptations, Mitigation: Energy production statistics by 10 world regions; Forests, Wood Production and Management by three zones: Tropical, Temperate, Boreal; separate chapters by physiographic types: Deserts, Mountain Regions, Wetlands, Cryosphere, Oceans, and Coastal Zones and small islands; country case studies, Agriculture by 8 continental-scale regions; Energy supply by 8 world regions
		Economic and Social Dimensions: Social Costs and Response Options by 6 economic regions
SR*: Regional Impacts* [10]	1998	10 continental-scale regions: Africa, Arctic and Antarctic, Australasia, Europe, Latin America, Middle East and Arid Asia, North America, Small Island States, Temperate Asia, Tropical Asia. Subdivisions applied in some regions; Vegetation shifts mapped by 9 biomes; Baseline (1990) Socio-Economic data provided by country and for all regions except polar.
SR*: Land-Use Change and Forestry* [11]	1998	9 Biomes; 15 land-use categories; National and Regional case studies.
SR*: Aviation* [12]	1999	Observed and projected emissions by 22 regional air routes; Inventories by 5 economic regions
SR*: Technology Transfer* [13]	2000	Country case studies; Indicators of technology transfer by 6-7 economic regions
SR*: Emissions Scenarios* [14]	2000	4 SRES world regions defined in common across integrated assessment models; 11 sub-regions; Driving Factors by 6 continental regions
Third Assessment Report (TAR) [15, 16, 17]	2001	*Climate*: gridded observations of Climate trends; 20 example Glaciers; 9 Biomes for Carbon Cycle; Circulation Regimes for model evaluation; 23 "Giorgi" regions for regional climate projections
		Impacts, adaptation and vulnerability: Example projections from 32 "modified-Giorgi" regions; Basins by continent; 5 Coastal types; Urban/Rural Settlements; Insurance by economic regions; 8 continental-scale regions equivalent to 1998 Special report but with single chapter for Asia; Subdivisions used for each region (Africa, Asia and Latin America by climate zones; North America by 6 core regions and 3 border regions)
		Mitigation: Country examples; Developed (Annex I) and Developing (non-Annex I); Various economic regions; Policies, Measures and Instruments by 4 blocs: OECD, Economies in Transition, China and Centrally Planned Asia, and Rest of the World.
SR*: Ozone Layer* [18]	2005	Various economic regions/countries depending on sources and uses of chemicals;
SR*: Carbon Capture and Storage* [19]	2005	CO_2 sources by 9 economic regions; potential storage facilities: by geological formation, by oil/gas wells, by ocean depth,; costs, by 4 economic groupings
Fourth Assessment Report (AR4) [20, 21, 22]	2007	*Climate*: Land-use types for surface forcing of climate; Observations by 19 "Giorgi" regions; Modes of variability for Model Evaluation; Attribution of climate change by 22 "Giorgi-type" regions and by 6 ocean regions; Climate statistics for 30 "Giorgi-type" regions; PDFs of projections for 26 regions; summary graphs for 8 continental regions
		Impacts, adaptation and vulnerability: Studies reporting observed impacts by 7 IPCC regions; comparison of TAR and AR4 climate projections for 32 Giorgi regions; Ecosystems by 11 biomes; Agriculture by latitudinal zone; Examples of Coastal mega-Deltas; Industry and settlement by continetal region; 8 continental regions, as in TAR, but Small Islands not Small Island States; Sub-regional summary maps for each region, using physiographic, biogeographic

		or geographic definitions; Example vulnerability maps at sub-national scale and globally by country.
		Mitigation: 17 global economic regions for GDP; Energy supply by continent, by economic regions, by 3 UNFCCC groupings; Trends in CO_2 emissions (and projections) , waste and carbon balance by economic regions,
***SR**: Renewable Energy Sources and Climate Change Mitigation* [23]	2011	Global maps showing potential resources for renewable energy: land suitability for bioenergy production, global irradiance for solar, geoethermal, hydropower, ocean waves/tidal range, wind); Various economic/continental regions: installed capacity (realised vs. potential), types of technologies, investment cost, cost effectiveness, various scenario-based projections; Country comparisons of deployment and uptake of technologies, share of energy market.
***SR**: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [24]	2012	Trends in observed (tables) and projected (maps and tables) climate extremes (Tmax, Tmin, heat waves, heavy precipitation and dryness) by 26 sub-continental regions covering most land areas of the globe; Attribution studies of return periods of extreme temperatures for 15 "Giorgi-type" regions; Gridded global maps of projected extremes of temperature, precipitation, windspeed, dry spells and soil moisture anomalies; Continental-scale estimates of projected changes in impacts of extremes (floods, cyclones, coastal inundation) as well as frequencies of observed climate extremes and their estimated costs); Distinctions drawn between local, country and international/global actors with respect to risk management and its financing.

1. IPCC (1990c), 2. IPCC (1990a); 3. IPCC (1990b); 4. IPCC (1992b); 5. IPCC (1992a); 6. IPCC (1994) 7. IPCC (1996c); 8. IPCC (1996b); 9. IPCC (1996a); 10. IPCC (1998b); 11. IPCC (1998a); 12. IPCC (1999); 13. IPCC (2000a), 14. IPCC (2000b); 15. IPCC (2001c); 16. IPCC (2001a); 17. IPCC (2001b); 18. IPCC/TEAP (2005); 19. IPCC (2005); 20. IPCC (2007c); 21. IPCC (2007a); 22. IPCC (2007b); 23. IPCC (2011); 24. IPCC (2012)

Table S21-2: [Proposed that this be moved supplementary material] Countries and territories of the world, their regional treatment in this report and some other illustrative groupings of relevance for international climate change policy making. Sources (status in May 2012): AOSIS (2012), Arctic Council (2012), European Commission (2012), G77 (2012), OECD (2012), OHRLLS (2012), OPEC (2012), Secretariat of the Antarctic Treaty (2012), UNCLOS (2012), UNFCCC (1992, 1998, 2012). [If supplementary material, possibly to be used in conjunction with an interactive map and other statistical information, e.g. population, GDP, HDI?]

UN member state and other territories (+)	Chapter of this Report	UNFCCC	Annex B	OECD	OECD ODA	LLDCs	SIDS	Transition Economies	AOSIS	G77 and China	OPEC	European Union	Antarctic Treaty	Arctic Council	UNCOLS
Afghanistan	24	3			1	1				1					2
Albania	23	4			4			1							1
Algeria	22	3			4					1	1				1
American Samoa (+)	29						2		2						
Andorra	23														
Angola	22	3			1					1	1				1
Anguilla (+)	29				4		2								
Antigua and Barbuda	29	3			4		1		1	1					1
Argentina	27, 28	3			4					1			1		1
Armenia	23	4			3	1		1							1
Aruba (+)	29						2								
Australia	25, 28	2	1	1									1		1
Austria	23	2	1	1								1	2		1
Azerbaijan	24	3			4	1		1							
Bahamas	29	3					1		1	1					1
Bahrain	24	3					1			1					1
Bangladesh	24	3			1					1					1
Barbados	29	3					1		1	1					1
Belarus	23	3			4			1					2		1
Belgium	23	2	1	1								1	1		1
Belize	27	3			3		1		1	1					1
Benin	22	3			1					1					1
Bhutan	24	3			1	1				1					2
Bolivia	27	3			3	1				1					1
Bosnia and Herzegovina	23	3			4			1		1					1
Botswana	22	3			4	1				1					1
Brazil	27	3		3	4					1			1		1

UN member state and other territories (+)	Chapter of this Report	UNFCCC	Annex B	OECD	OECD ODA	LLDCs	SIDS	Transition Economies	AOSIS	G77 and China	OPEC	European Union	Antarctic Treaty	Arctic Council	UNCOLS
British Virgin Islands (+)	29						2								
Brunei Darussalam	24	3								1					1
Bulgaria	23	1	1									1	1		1
Burkina Faso	22	3			1	1				1					1
Burundi	22	3			1	1				1					2
Cambodia	24	3			1					1					2
Cameroon	22	3			3					1					1
Canada	26, 28	2	1	1									2	1	1
Cape Verde	29	3			3		1		1	1					1
Central African Republic	22	3			1	1				1					2
Chad	22	3			1	1				1					1
Chile	27, 28	3		1	4					1			1		1
China	24	3		3	4					1			1		1
Colombia	27	3			4					1			2		2
Commonwealth of the Northern Mariana Islands (+)	29						2								
Comoros	29	3			1		1		1	1					1
Congo	22	3			3					1					1
Cook Islands (+)	29	3			4		2		1						1
Costa Rica	27	3			4					1					1
Côte d'Ivoire	22	3			3					1					1
Croatia	23	1	1					1				2			1
Cuba	29	3			4		1		1	1			2		1
Cyprus	29	3							1			1			1
Czech Republic	23	1	1	1								1	2		1
Democratic People's Republic of Korea	24	3			2					1			2		2
Democratic Republic of the Congo	22	3			1					1					1
Denmark	23, 28	2	1	1								1	2	1	1
Djibouti	22	3			1					1					1
Dominica	27	3			4		1		1	1					1
Dominican Republic	27	3			4		1			1					1
Ecuador	27	3			4					1	1		1		
Egypt	22	3			3					1					1

UN member state and other territories (+)	Chapter of this Report	UNFCCC	Annex B	OECD	OECD ODA	LLDCs	SIDS	Transition Economies	AOSIS	G77 and China	OPEC	European Union	Antarctic Treaty	Arctic Council	UNCOLS
El Salvador	27	3			3					1					2
Equatorial Guinea	22	3			1					1					1
Eritrea	22	3			1					1					
Estonia	23	1	1	1								1	2		1
Ethiopia	22	3			1	1				1					2
European Union (+)	23	2	1												1
Fiji	29	3			3		1		1	1					1
Finland	23, 28	2	1	1								1	1	1	1
France	23	2	1	1								1	1	2	1
French Polynesia (+)	29						2								
Gabon	22	3			4					1					1
Gambia	22	3			1					1					1
Georgia	24	3			3			1							1
Germany	23	2	1	1								1	1	2	1
Ghana	22	3			3					1					1
Greece	23	2	1	1								1	2		1
Grenada	29	3			4		1		1	1					1
Guam (+)	29						2		2						
Guatemala	27	3			3					1			2		1
Guinea	22	3			1					1					1
Guinea-Bissau	22	3			1		1		1	1					1
Guyana	27	3			3		1		1	1					1
Haiti	27	3			1		1		1	1					1
Holy See (+)	23														
Honduras	27	3			3					1					1
Hungary	23	1	1	1								1	2		1
Iceland	23, 28	2	1	1								2		1	1
India	24	3		3	3					1			1		1
Indonesia	24	3		3	3					1					1
Iran (Islamic Republic of)	24	3			4					1	1				2
Iraq	24	3			3					1	1				1
Ireland	23	2	1	1								1			1

UN member state and other territories (+)	Chapter of this Report	UNFCCC	Annex B	OECD	OECD ODA	LLDCs	SIDS	Transition Economies	AOSIS	G77 and China	OPEC	European Union	Antarctic Treaty	Arctic Council	UNCOLS
Israel	24	3		1											
Italy	23	2	1	1								1	1		1
Jamaica	29	3			4		1		1	1					1
Japan	24	2	1	1									1		1
Jordan	24	3			4					1					1
Kazakhstan	24	4			4	1		1							
Kenya	22	3			2					1					1
Kiribati	22	3			1		1		1						1
Kosovo (+)	23				3										
Kuwait	24	3								1	1				1
Kyrgyzstan	24	3			2	1		1							
Lao People's Democratic Republic	24	3			1	1				1					1
Latvia	23	1	1									1			1
Lebanon	24	3			4					1					1
Lesotho	22	3			1	1				1					1
Liberia	22	3			1					1					1
Libya	22	3			4					1	1				2
Liechtenstein	23	1	1												2
Lithuania	23	1	1									1			1
Luxembourg	23	2	1	1								1			1
Madagascar	22	3			1					1					1
Malawi	22	3			1	1				1					1
Malaysia	24	3			4					1			2		1
Maldives	29	3			4		1		1	1					1
Mali	22	3			1	1				1					1
Malta	29	3							1			1			1
Marshall Islands	29	3			3		1		1	1					1
Mauritania	22	3			1					1					1
Mauritius	29	3			4		1		1	1					1
Mexico	26	3		1	4										1
Micronesia (Federated States of)	29	3			3		1		1	1					1
Monaco	23	1	1										2		1

UN member state and other territories (+)	Chapter of this Report	UNFCCC	Annex B	OECD	OECD ODA	LLDCs	SIDS	Transition Economies	AOSIS	G77 and China	OPEC	European Union	Antarctic Treaty	Arctic Council	UNCOLS
Mongolia	24	3			3	1				1					1
Montenegro	23	3			4			1				2			1
Montserrat (+)	29				4		2								
Morocco	22	3			3					1					1
Mozambique	22	3			1					1					1
Myanmar	24	3			1					1					1
Namibia	22	3			4					1					1
Nauru	29	3			4		1		1	1					1
Nepal	24	3			1	1				1					1
Netherlands	23	2	1	1								1	1	2	1
Netherlands Antilles (+)	29						2		2						
New Caledonia (+)	29						2								
New Zealand	25, 28	2	1	1									1		1
Nicaragua	27	3			3					1					1
Niger	22	3			1	1				1					2
Nigeria	22	3			3					1	1				1
Niue (+)	29	3			3		2		1						1
Norway	23, 28	2	1	1									1	1	1
Oman	24	3								1					1
Pakistan	24	3			3					1			2		1
Palau	29	3			4		1		1						1
Panama	27	3			4					1					1
Papua New Guinea	24	3			3		1		1	1			2		1
Paraguay	27	3			3	1				1					1
Peru	27	3			4					1			1		
Philippines	24	3			3					1					1
Poland	23	1	1	1								1	1	2	1
Portugal	23	2	1	1								1	2		1
Puerto Rico (+)	29						2								
Qatar	24	3								1	1				1
Republic of Korea	24	3		1									1		1
Republic of Moldova	23	4			3	1		1							1

UN member state and other territories (+)	Chapter of this Report	UNFCCC	Annex B	OECD	OECD ODA	LLDCs	SIDS	Transition Economies	AOSIS	G77 and China	OPEC	European Union	Antarctic Treaty	Arctic Council	UNCOLS
Romania	23	1	1									1	2		1
Russian Federation	23, 24, 28	1	1	2				1					1	1	1
Rwanda	22	3			1	1				1					2
Saint Kitts and Nevis	29	3			4		1		1	1					1
Saint Lucia	29	3			4		1		1	1					1
Saint Vincent and the Grenadines	29	3			4		1		1	1					1
Samoa	29	3			1		1		1	1					1
San Marino	23	3													
Sao Tome and Principe	29	3			1		1		1	1					1
Saudi Arabia	24	3								1	1				1
Senegal	22	3			1					1					1
Serbia	23	3			4			1				2			1
Seychelles	29	3			4		1		1	1					1
Sierra Leone	22	3			1					1					1
Singapore	29	3					1		1	1					1
Slovakia	23	1	1	1								1	2		1
Slovenia	23	1	1	1								1			1
Solomon Islands	29	3			1		1		1	1					1
Somalia	22	3			1					1					1
South Africa	22	3		3	4					1			1		1
South Sudan	22				2										
Spain	23	2	1	1								1	1	2	1
Sri Lanka	24	3			3					1					1
St Helena (+)	29				4										
Sudan	22	3			1					1					1
Suriname	25	3			4		1		1	1					1
Swaziland	22	3			3	1				1					2
Sweden	23, 28	2	1	1								1	1	1	1
Switzerland	23	2	1	1									2		1
Syrian Arab Republic	22	3			3					1					
Tajikistan	24	3			2	1		1		1					
Thailand	24	3			4					1					1

UN member state and other territories (+)	Chapter of this Report	UNFCCC	Annex B	OECD	OECD ODA	LLDCs	SIDS	Transition Economies	AOSIS	G77 and China	OPEC	European Union	Antarctic Treaty	Arctic Council	UNCOLS
The former Yugoslav Republic of Macedonia	23	3			4	1		1				2			1
Timor-Leste	24	3			1		1			1					
Togo	22	3			1					1					1
Tokelau (+)	29				3										
Tonga	29	3			3		1		1	1					1
Trinidad and Tobago	29	3					1		1	1					1
Tunisia	22	3			4					1					1
Turkey	23	1		1	4							2	2		
Turkmenistan	24	4			3	1		1		1					
Tuvalu	29	3			1		1		1						1
U.S. Virgin Islands (+)	29						2		2						
Uganda	22	3			1	1				1					1
Ukraine	23	1	1		3			1					1		1
United Arab Emirates	24	3								1	1				2
United Kingdom of Great Britain and Northern Ireland	23, 28	2	1	1								1	1	2	1
United Republic of Tanzania	22	3			1					1					1
United States of America	26, 28	2	1	1									1	1	
Uruguay	27	3			4					1			1		1
Uzbekistan	24	4			3	1		1							
Vanuatu	29	3			1		1		1	1					1
Venezuela (Bolivarian Republic of)	27	3			4					1	1		2		
Viet Nam	24	3			3					1					1
Wallis and Futuna (+)	29				4										
West Bank and Gaza Strip (+)	24				3					1					
Yemen	24	3			1					1					1
Zambia	22	3			1	1				1					1
Zimbabwe	22	3			2	1				1					1

Key to country groupings and numerical codes. **UNFCCC** (United Nations Framework Convention on Climate Change) Parties – 1: Annex I, 2: Annex II, 3: Non-Annex I, 4: Non-Annex I Special Decision; **Annex B** Parties to the Kyoto Protocol – 1: Annex B; **OECD** (Organisation for Economic Co-operation and Development) – 1: Member, 2: Accession process, 3: Enhanced engagement; **OECD ODA** (Overseas Development Assistance) – 1: Least developed, 2: Other low income, 3: Lower middle income, 4: Upper middle income; **LLCDs** (Landlocked Developing Countries) – 1: Member; **SIDS** (Small Island Developing States) – 1: UN Member, 2: Non-UN/Associate; **Transition Economies** – 1: UN designated; **AOSIS** (Alliance of Small Island States) – 1: Member, 2: Observer; **G77** (Group of 77) **and China** – 1: Member; **OPEC** (Organization of the Petroleum Exporting Countries) – 1: Member; **European Union** – 1: Member State, 2: Candidate; **Antarctic Treaty** Parties – 1: Consultative, 2: Non-Consultative; **Arctic Council** – 1: Member, 2: Permanent Observer; **UNCOLS** (United Nations Convention on the Law of the Sea) – 1: Ratified, 2: Signed but not Ratified.

Table 21-3: [PLACEHOLDER] Comparative table that will summarise vulnerability findings in key systems according to the first half of WG2's contribution in the different regions as laid out in the second half of WG2's contribution.

	Urban	Rural	Food & Water	Coasts	Ecosystems	Industry and Infrastructure
Africa						
Europe						
Asia						
Australasia						
North America						
Central and South America						
Polar Regions						
Small Islands						
Open Oceans						

Table 21-4: [PLACEHOLDER] Comparative table that will summarise impacts findings in key systems according to the first half of WG2's contribution in the different regions as laid out in the second half of WG2's contribution.

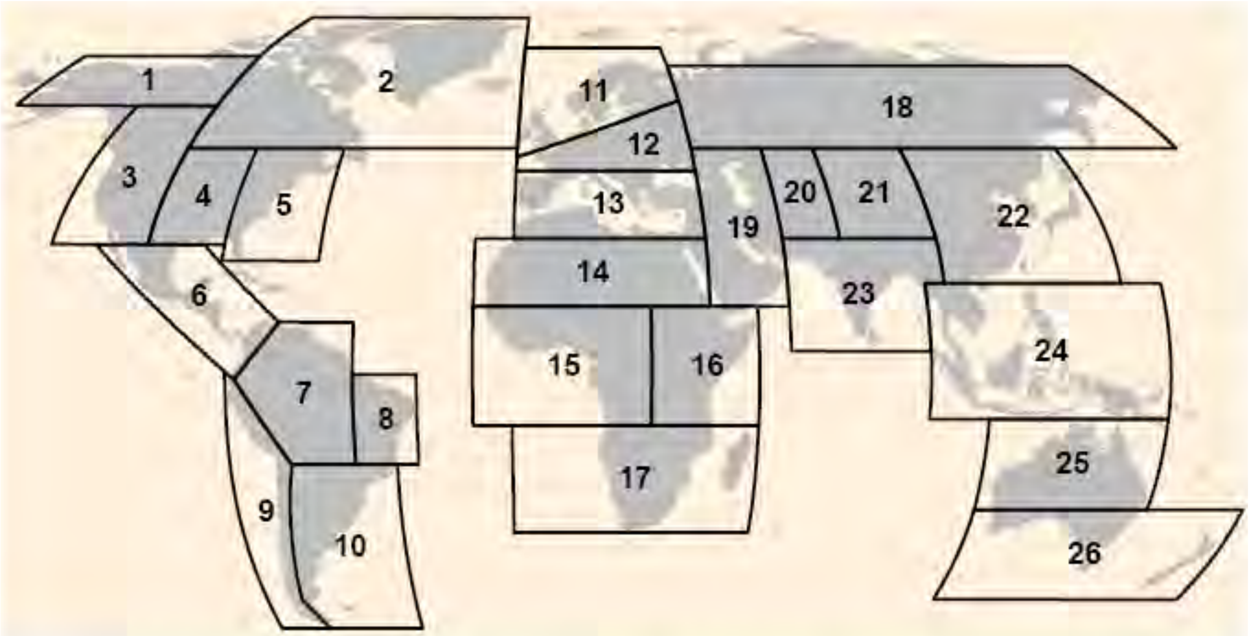
	Urban	Rural	Food & Water	Coasts	Ecosystems	Industry and Infrastructure
Africa						
Europe						
Asia			Example of what could be here: Rice growing areas in Mekong, Red River, Irrawaddy and Ganges-Brahmaputra Deltas (Chapter 5)			
Australasia						
North America						
Central and South America						
Polar Regions						
Small Islands						
Open Oceans						

Table 21-5: [PLACEHOLDER] Comparative table that will summarise adaptation issues in key systems according to the first half of WG2's contribution in the different regions as laid out in the second half of WG2's contribution.

	Urban	Rural	Food & Water	Coasts	Ecosystems	Industry and Infrastructure
Africa						
Europe						
Asia						
Australasia						
North America						
Central and South America						
Polar Regions						
Small Islands						
Open Oceans						

Table 21-6: [PLACEHOLDER] Comparative table that will summarise sectoral issues in key systems according to the first half of WG2's contribution in the different regions as laid out in the second half of WG2's contribution.

	Urban	Rural	Food & Water	Coasts	Ecosystems	Industry and Infrastructure
Africa						
Europe						
Asia						
Australasia						
North America						
Central and South America						
Polar Regions						
Small Islands						
Open Oceans						



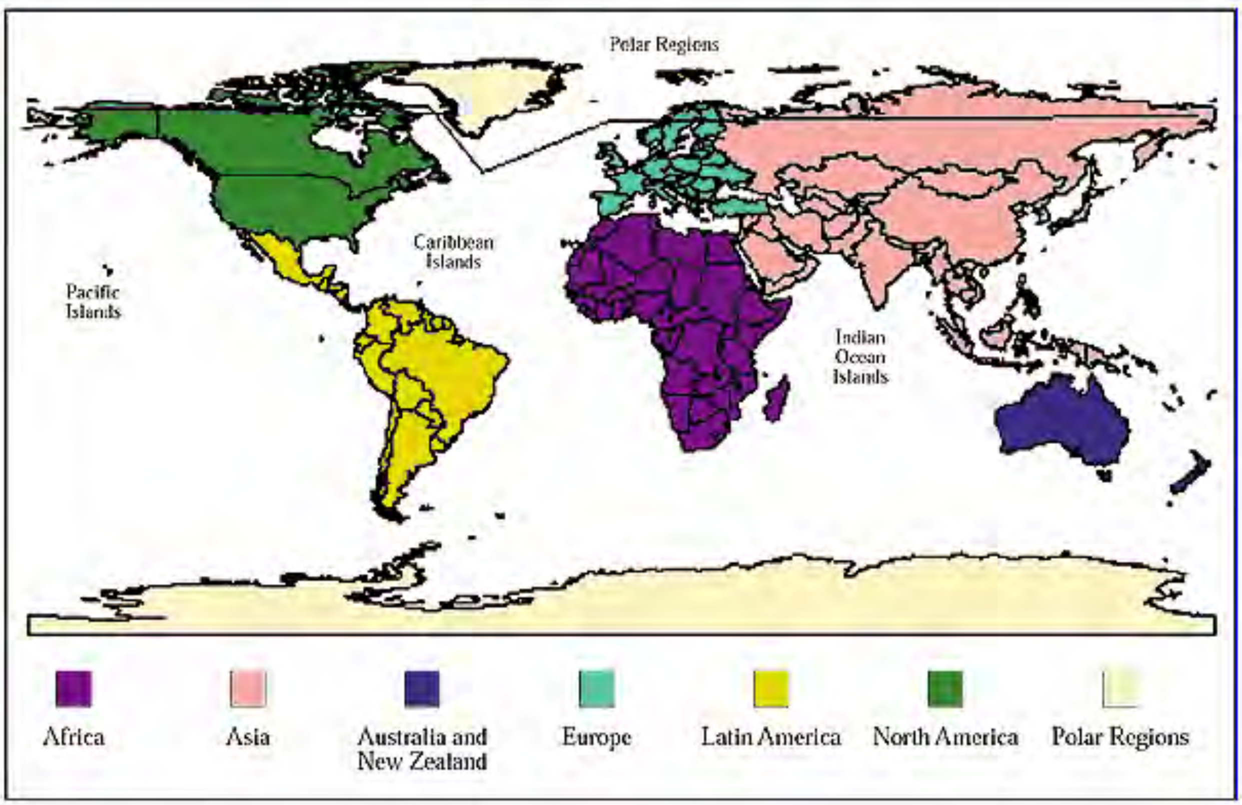


Figure 21-1: [PLACEHOLDER] Maps showing the 26 regions (land areas only) used to summarise projected changes in climate in this chapter (upper panel – IPCC, 2012) and the regions defined for Chapters 22-29 in Part B (lower panel – IPCC, 2001). Note that information is also provided in this chapter on projected climate over the open oceans. [Maps to be redrawn and combined when climate regions and AR5 chapter regions clarified]

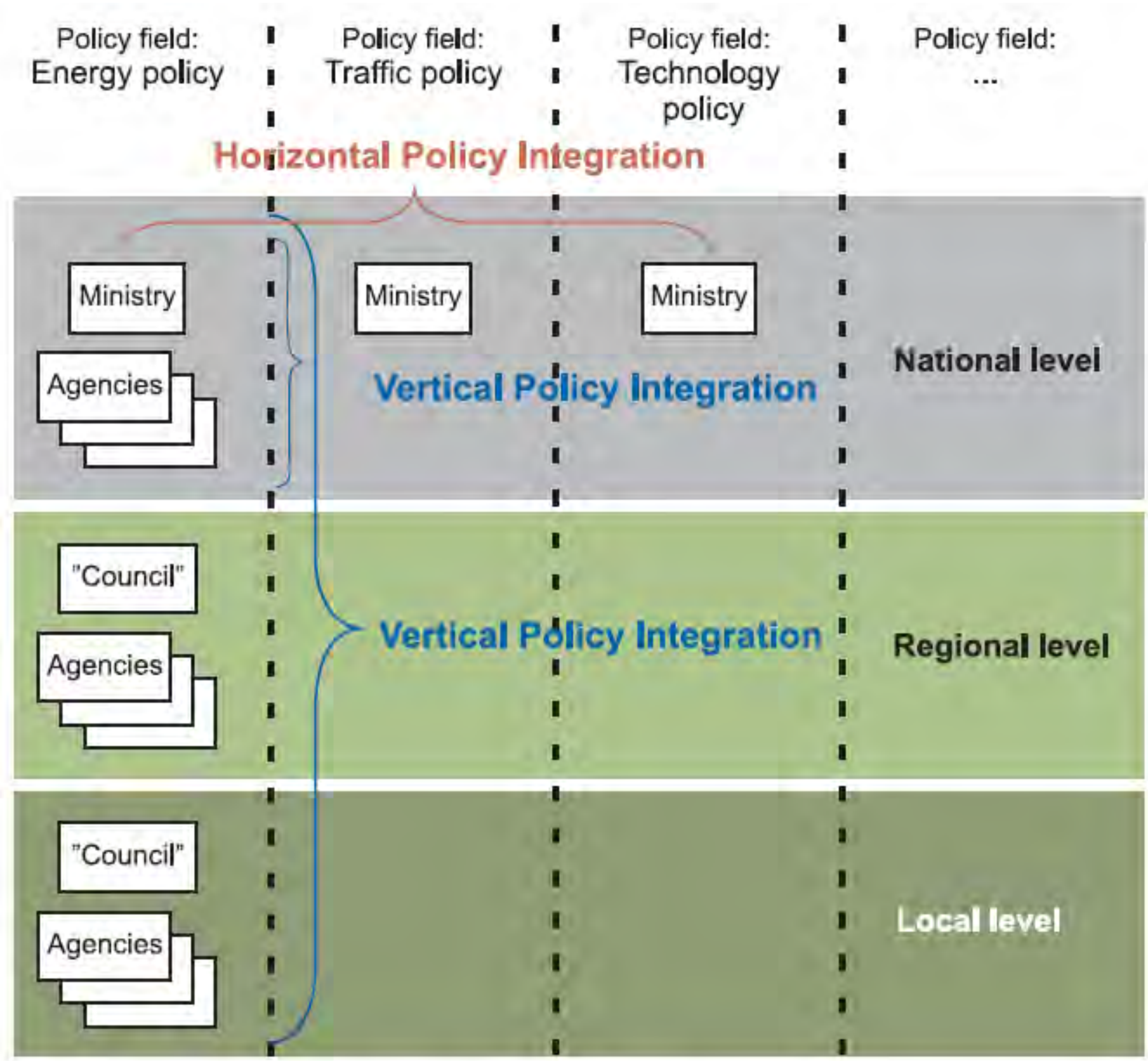


Figure 21-2: Horizontal and vertical climate policy integration (Mickwitz et al. 2009). Vertical policy integration can occur within as well as between levels, and may extend to supra-national and global levels (not shown).
[possibly redraw to include international dimensions]

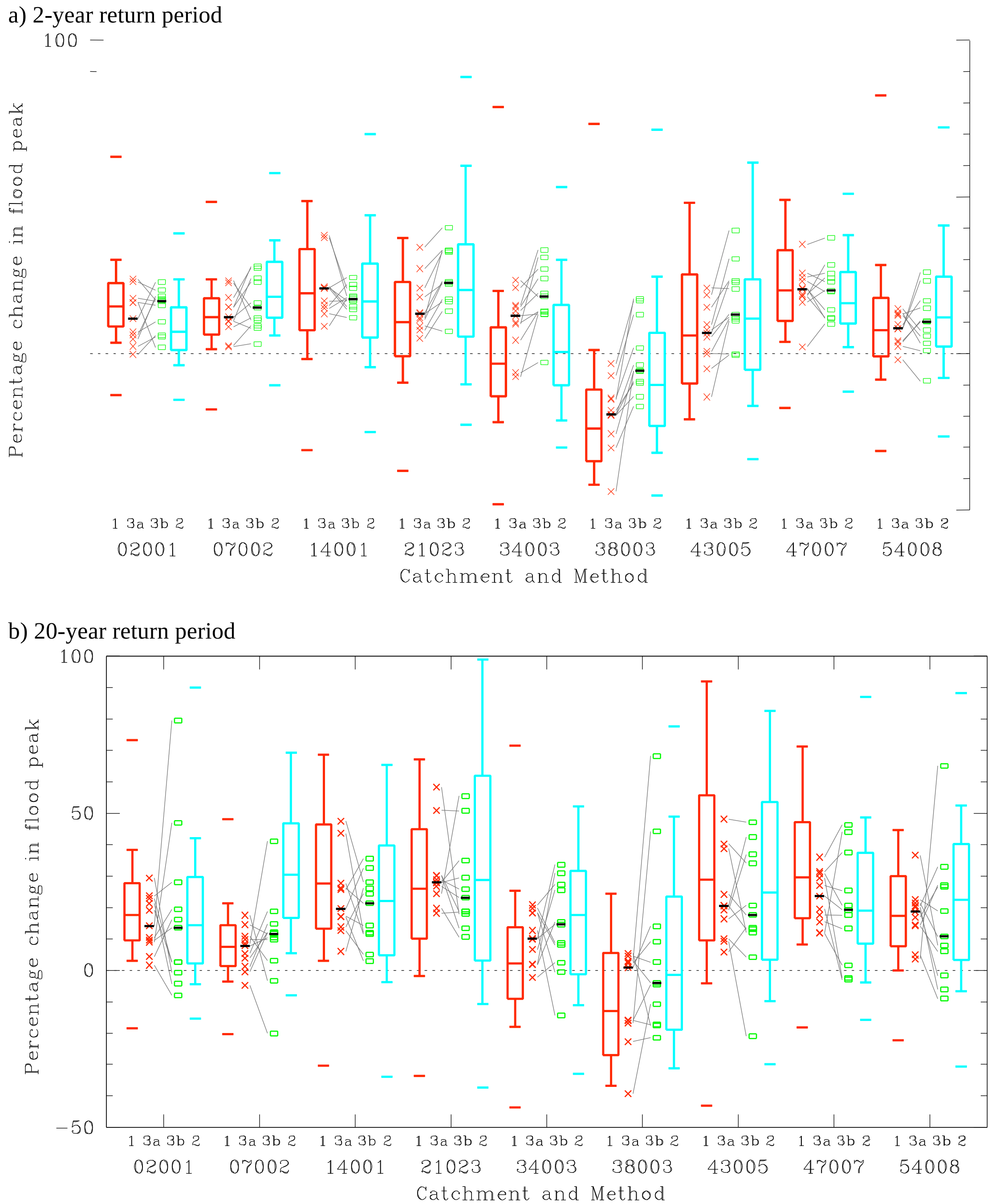


Figure 21-3: The range of percentage change in flood peaks for nine UK catchments at the a) 2-year and b) 20-year return period. Box-and-whisker plots are used to summarise results when using 10,000 UKCP09 Sampled Data (Murphy et al. 2009) change factors (red) and 100 sets of UKCP09 current and future Weather Generator time-series (cyan). Also plotted, are the results when using 11 sets of RCM-derived change factors (red crosses) and when using 11 sets of RCM current and future times-series (green rectangles). The box delineates the 25th-75th percentile range and the whiskers the 10th-90th percentile range, with the median (50th percentile) shown by the line dividing the box. Additional markers outside the whiskers indicate the minima and maxima, if within the plotted range of -50 to +100. The points derived from the RCM results are joined for the corresponding members of the RCM ensemble (grey lines), and the medians for these methods are shown by black horizontal bars.

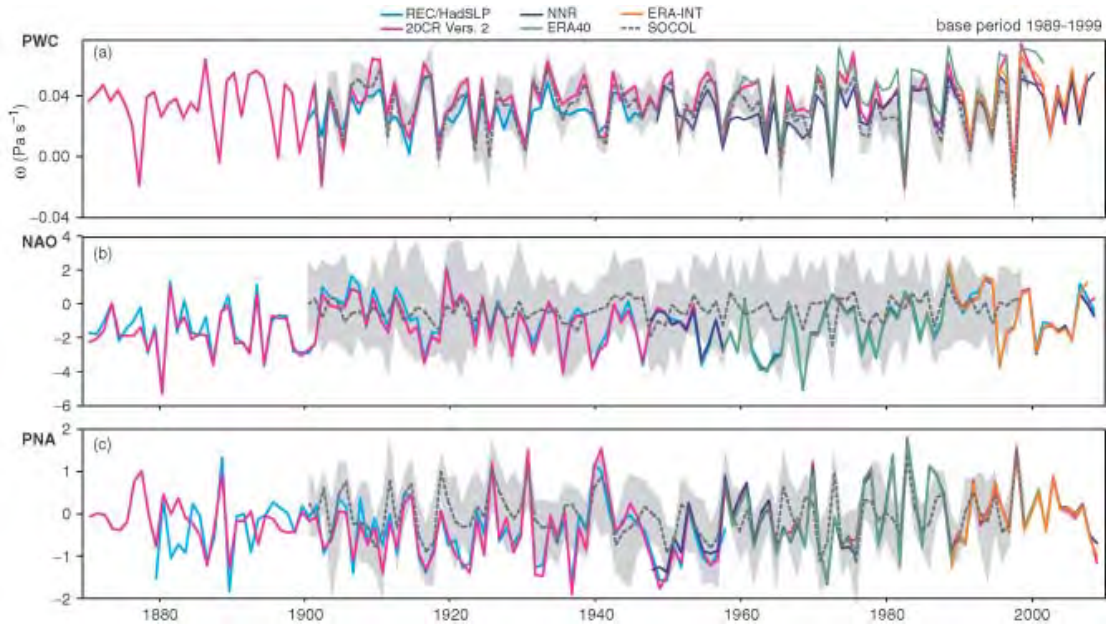


Figure 21-4: Time series of seasonally averaged climate indices representing (a) the tropical September to January Pacific Walker Circulation (PWC), (b) the December to March North Atlantic Oscillation (NAO), and (c) the December to March Pacific North America (PNA) pattern. Indices are calculated from various sources: 20CRv2 (pink); statistical reconstructions using Bronnimann *et al.* (2009) for the PWC, Griesser *et al.* (2010) for the PNA, and HadSLP2 (Allan and Ansell, 2006) for the NAO (all cyan); NCEP–NCAR reanalyses (NNR; dark blue); ERA-40 (green); ERA-Interim (orange); and SOCOL ensemble mean (dark grey). The light grey shading indicates the minimum and maximum range of the SOCOL ensemble. All indices are computed with respect to the overlapping 1989–1999 period. Indices are defined as in Brönnimann *etal.* (2009).

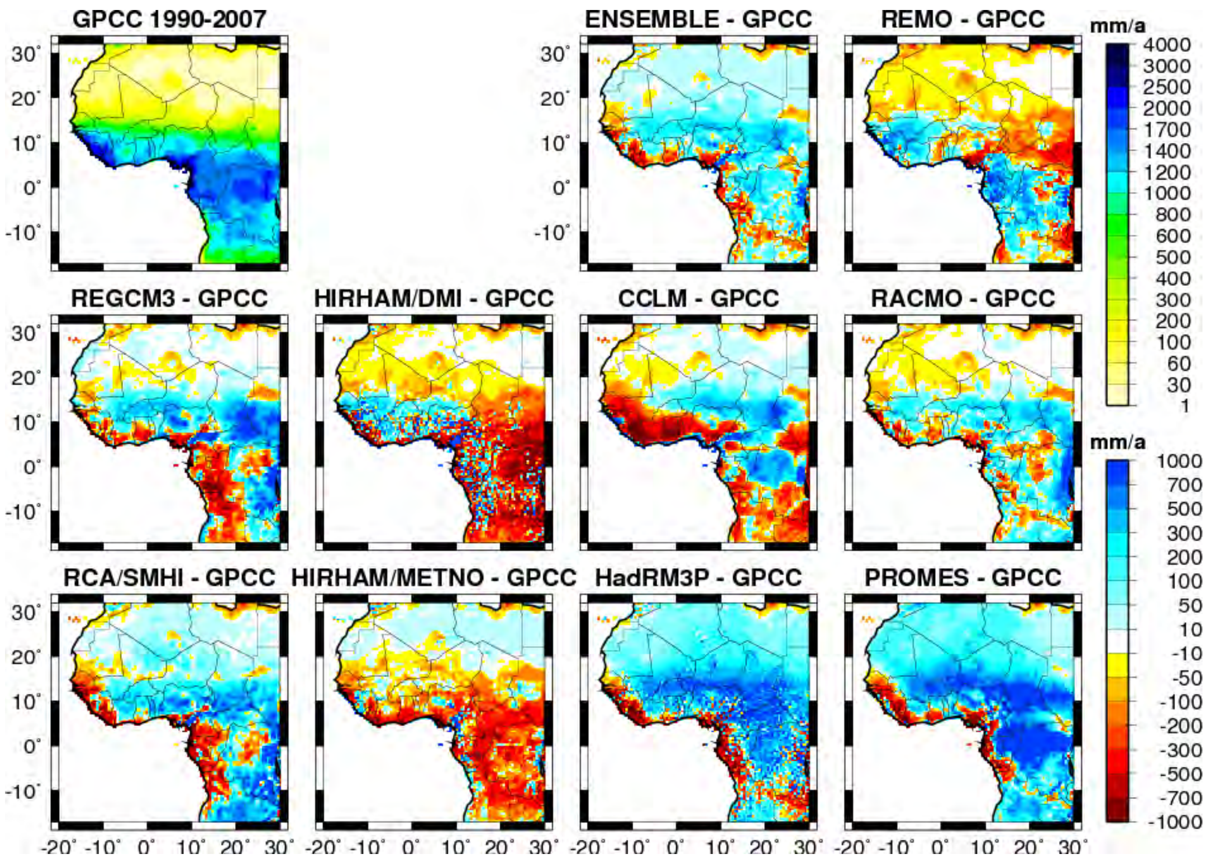


Figure 21-5: Observed 1990-2007 annual precipitation climatology from GPCC (Rudolf et al., 2011), top left, and, in the remaining panels, related systematic errors in 9 individual regional climate model simulations driven by the ERA-Interim reanalyses (Dee et al., 2011) and in the multi-model ensemble mean.

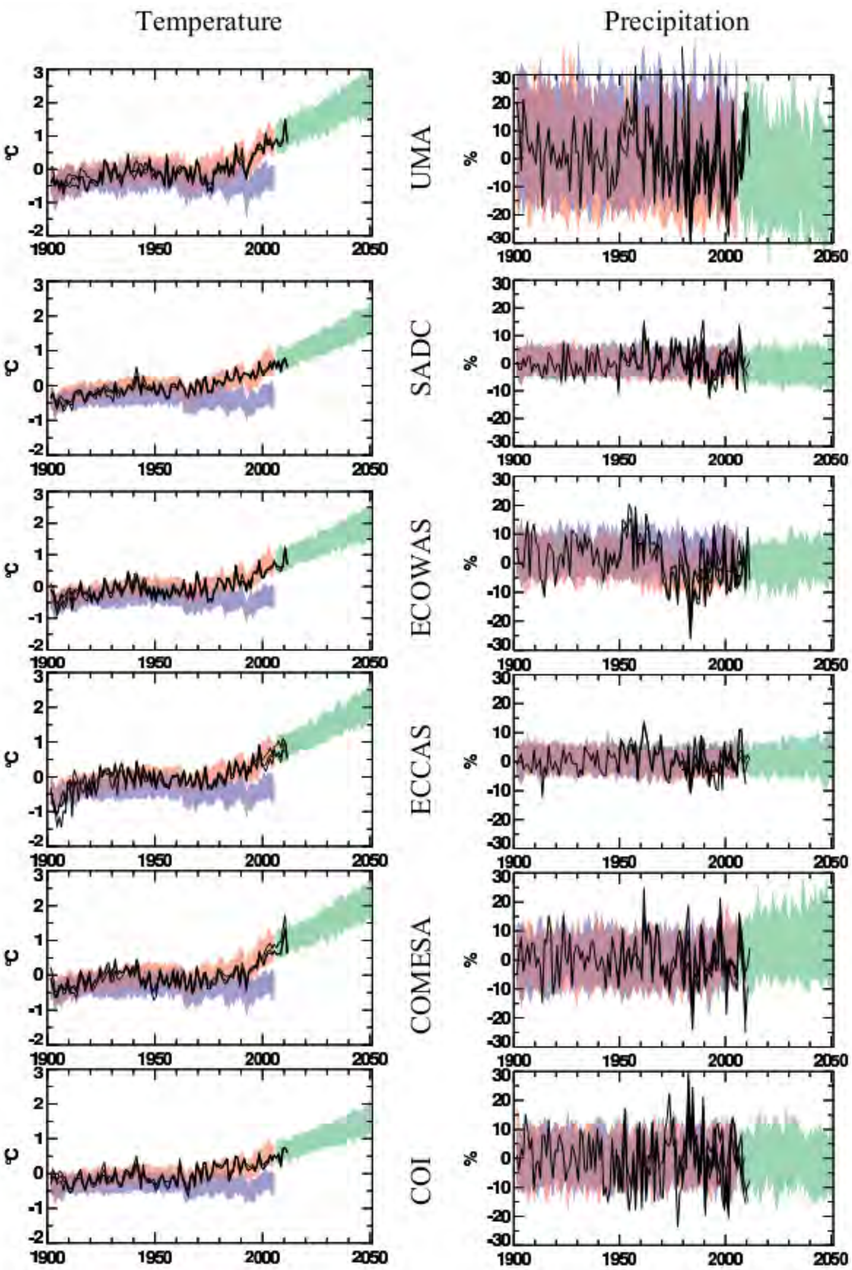


Figure 21-6: Variations in past and future regional climate over Africa. Precipitation plots cover land territory only, while temperature plots cover both land and exclusive economic zone territory. Black lines show annual average values from observational datasets and coloured bands show the 10-90th percentile range of annual average values from 32 simulations from 12 climate models from the WCRP CMIP3 and CMIP5 projects (Meehl et al. 2007, Taylor et al. 2012). The pink band is from simulations driven with observed changes in all known external drivers over the 1901-2005 period. The blue band is from simulations driven with observed changes in natural external drivers only. The green band is from simulations running over 2006-2050 driven under either the SRES A1B or the RCP4.5 emissions scenario. Observed values are plotted as anomalies from their 1901-2005 averages. Model values are plotted as anomalies from their 1901-2005 averages in the simulation with all know drivers.

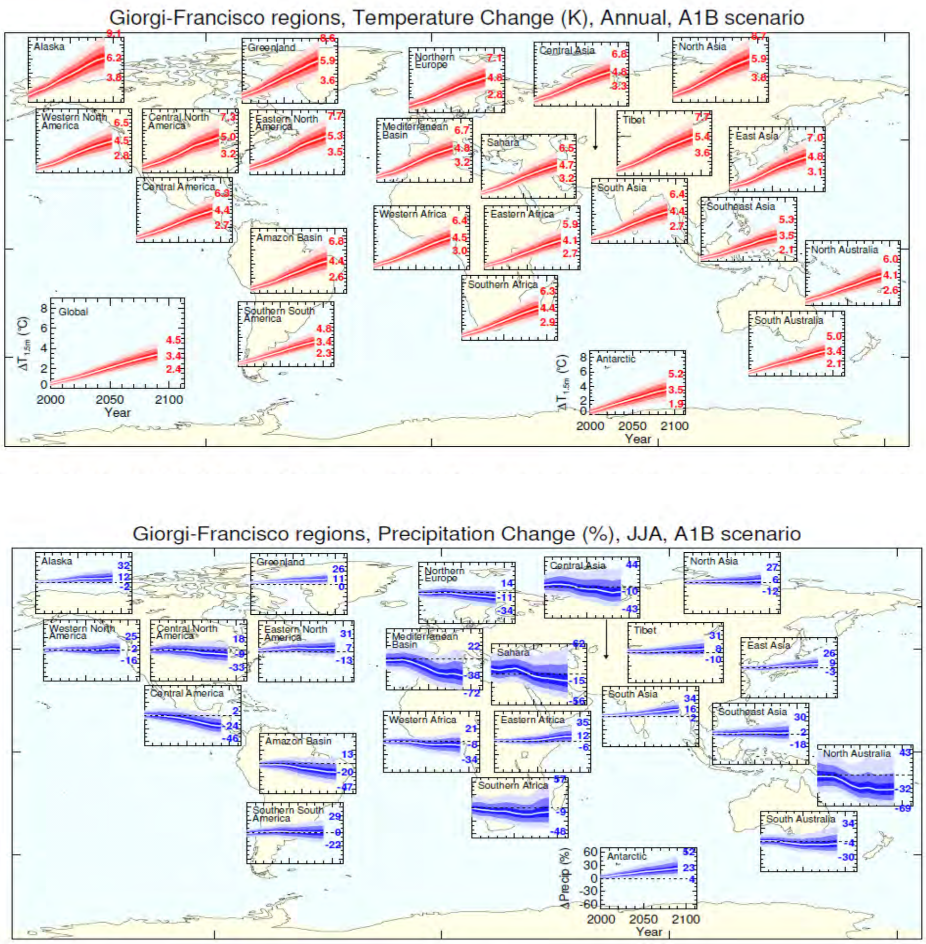


Figure 21-7: Evolution of the 5%, 17%, 33%, 50%, 66%, 83% and 95% percentiles of the distribution functions for annual surface air temperature changes (upper panel) and annual precipitation (lower panel) for the Giorgi-Francisco (2000) regions and the globe with the A1B forcing scenario. Twenty year means relative to the 1961-1990 baseline are plotted in decadal steps using a common y-axis scale. The 5%, 50% and 95% percentile values for the period 2080-2099 are displayed for each region. (From Harris et al. 2012)

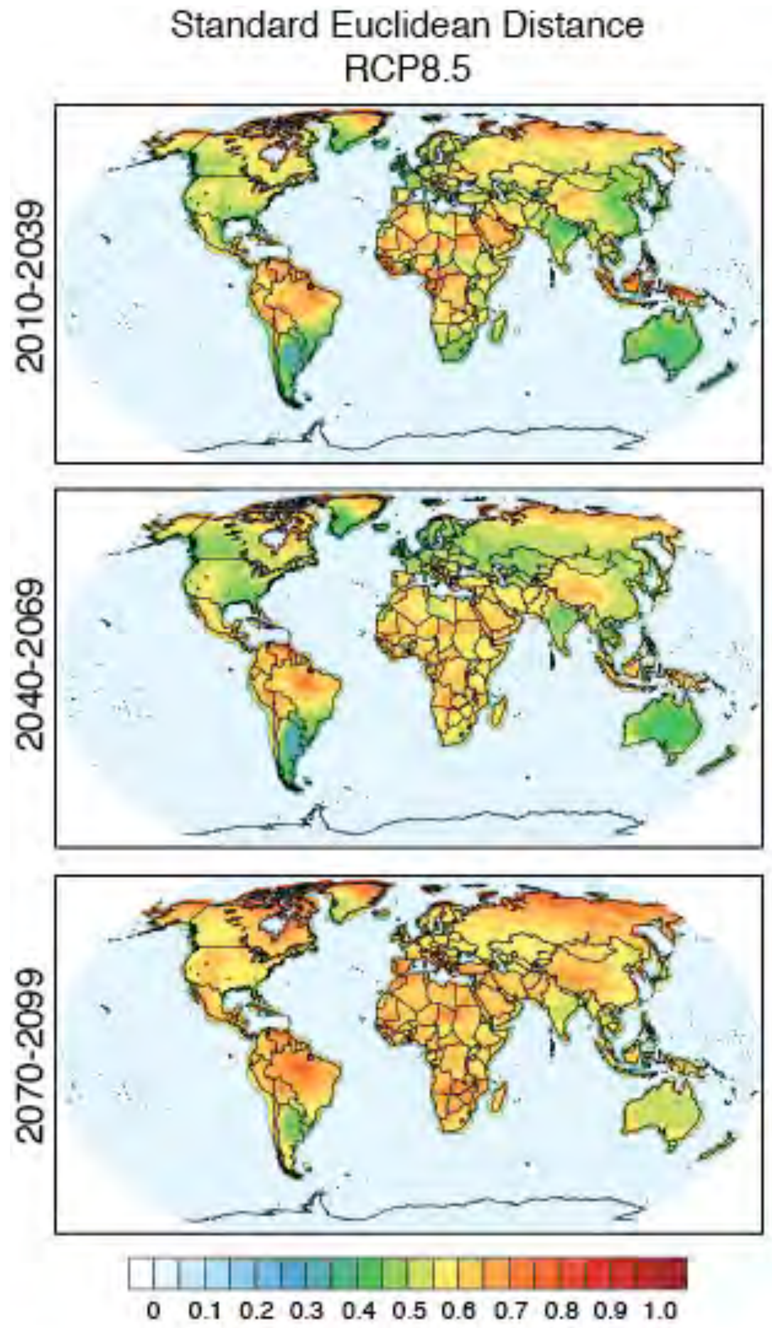


Figure 21-8: The relative aggregate climate change between the 1975-2005 period and the 2010-2039, 2040-2069 and 2070-2099 periods of RCP8.5. The aggregate climate change is calculated using the Standard Euclidean Distance (SED) across the 28-dimensional climate space formed by 7 climate variables in each of 4 seasons. The absolute values of change in each variable are normalized to the maximum global absolute value prior to calculating the SED. The SED values are then normalized to the maximum global SED value. Only land grid points north of 60˚S are used in the normalizations (From Diffenbaugh and Giorgi 2012).

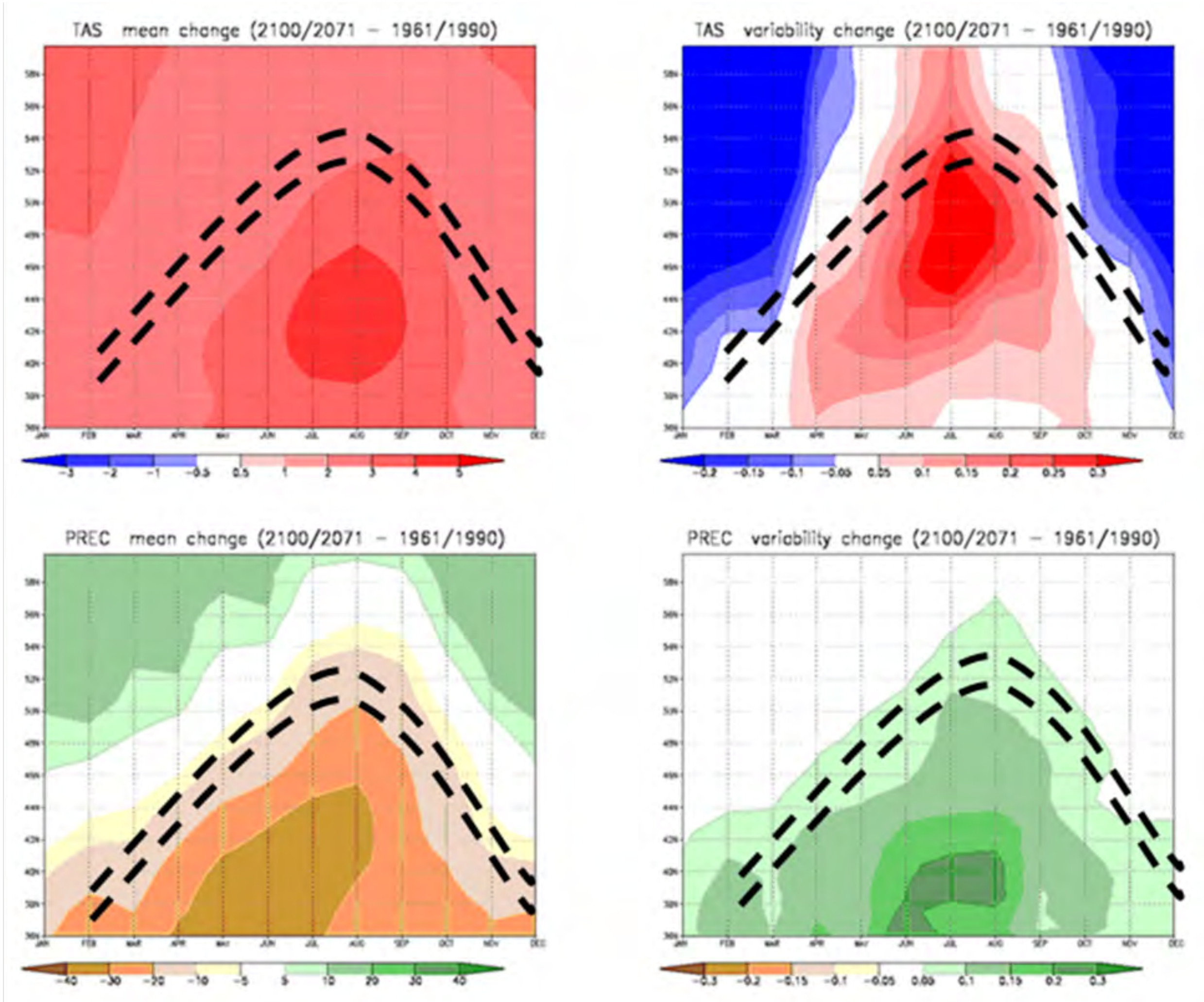


Figure 21-9: Monthly values of the zonally averaged changes in mean surface air temperature (top left panel), temperature interannual variability (as measured by the standard deviation, top right panel), mean precipitation (bottom left panel), precipitation interannual variability (as measured by the coefficient of variation) over Europe; CMIP3 ensemble, A1B scenario, 2071-2100 minus 1961-1990. Units are degrees C for temperature and % of 1961-1990 values for mean precipitation (the coefficient of variation is unitless). The zonal average is taken over the region between 10°W and 25°E. The dashed lines illustrate the European Climate Change Oscillation (ECO). From Giorgi and Coppola (2007).

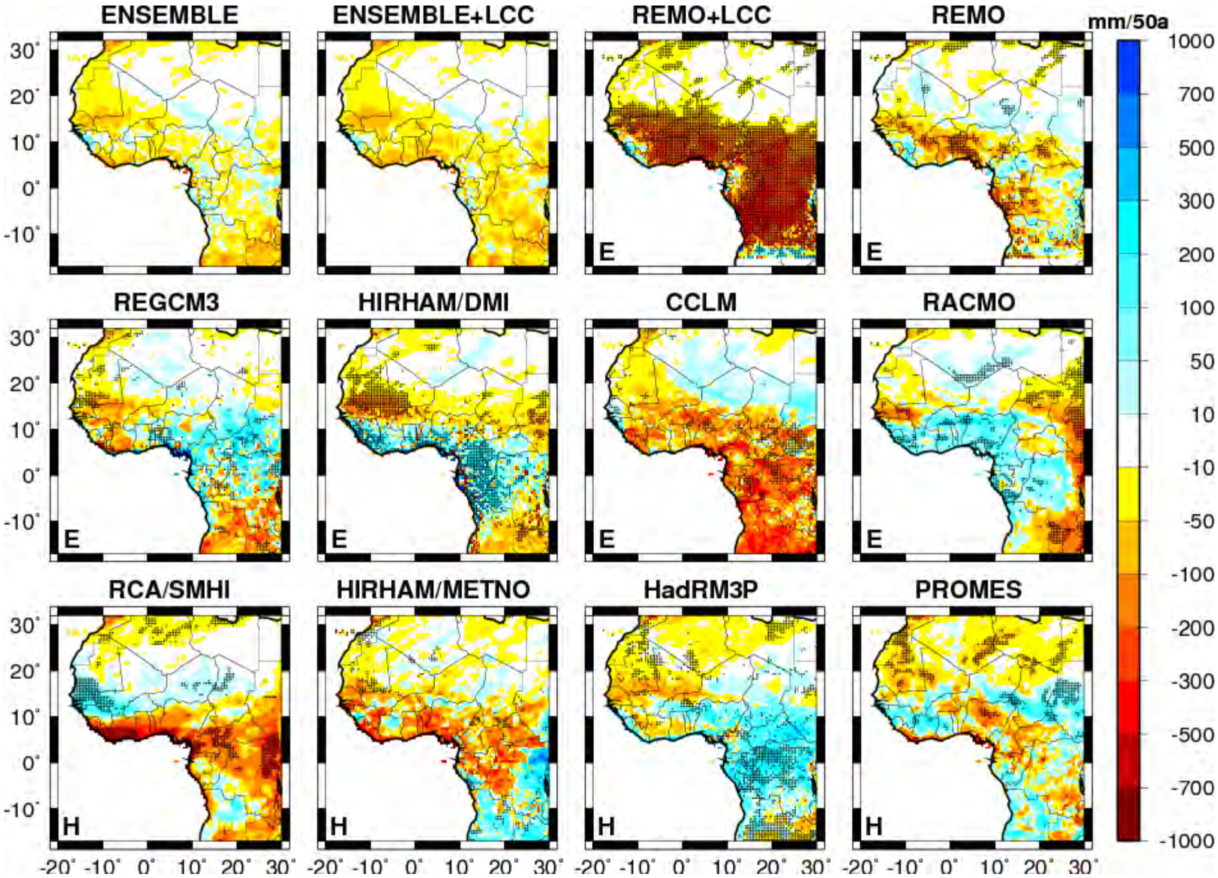


Figure 21-10: Linear changes of annual precipitation during the 2001-2050 period from 10 individual RCM experiments and the MME mean under the A1B emission scenario. The top middle panels also account for projected land cover changes (see text for further explanation). Note that the REMO trends in both panels arise from a three-member ensemble whereas all other RCMs are represented by one single simulation. Trends statistically significant at the 5% level are marked by black dots. (From Paeth et al. 2011)

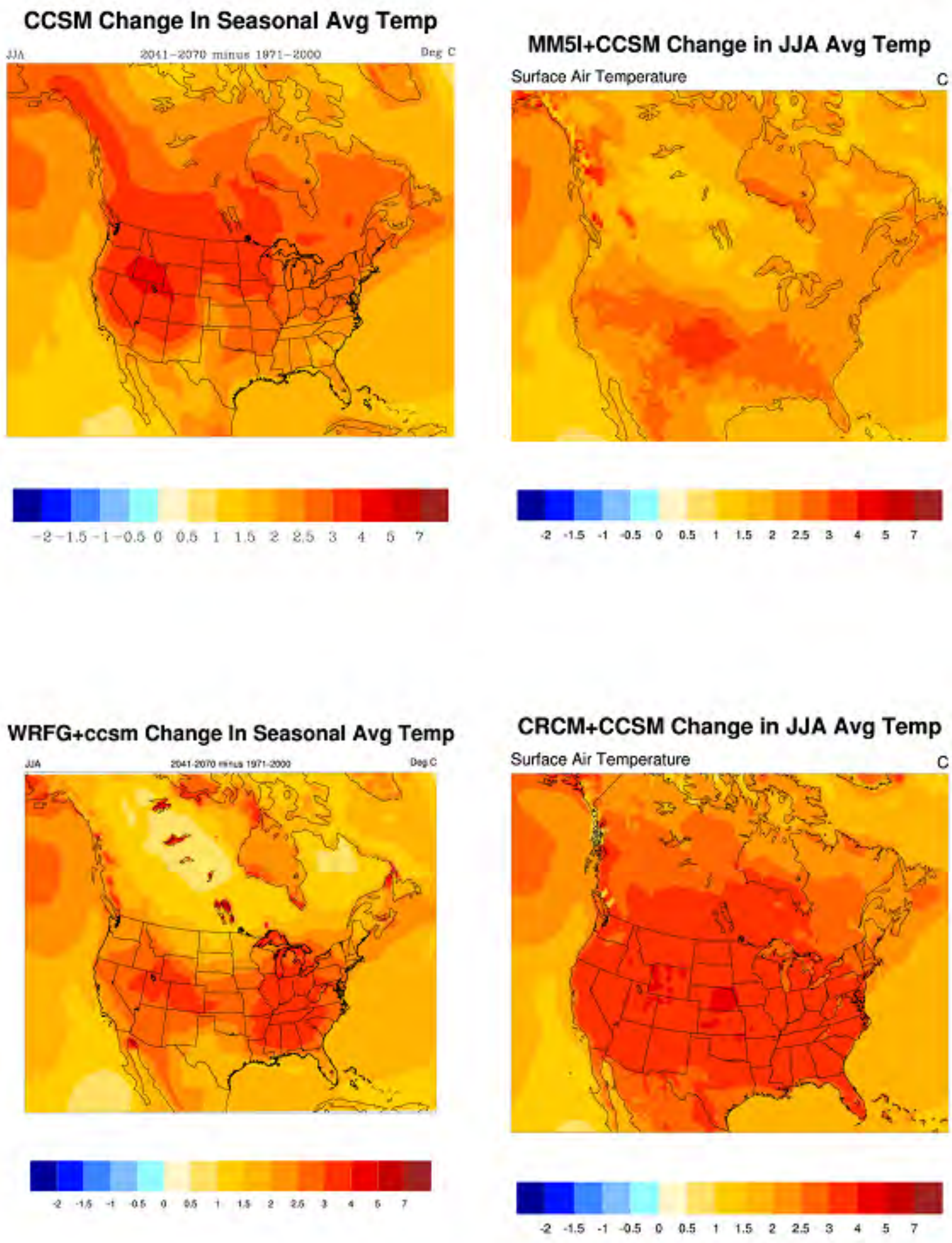


Figure 21-11: Change in summer (JJA) average temperature (2041-2070 minus 1971-2000) from (top left) the NCAR CCSM3, (top right) the MM5 regional climate model driven by the CCSM3; (bottom left) the WRF model, driven by CCSM3, and (bottom right) the Canadian CRCM, driven by CCSM3. Temperature is in °C. Data from the NARCCAP program. (From Mearns et al., 2009, 2011)

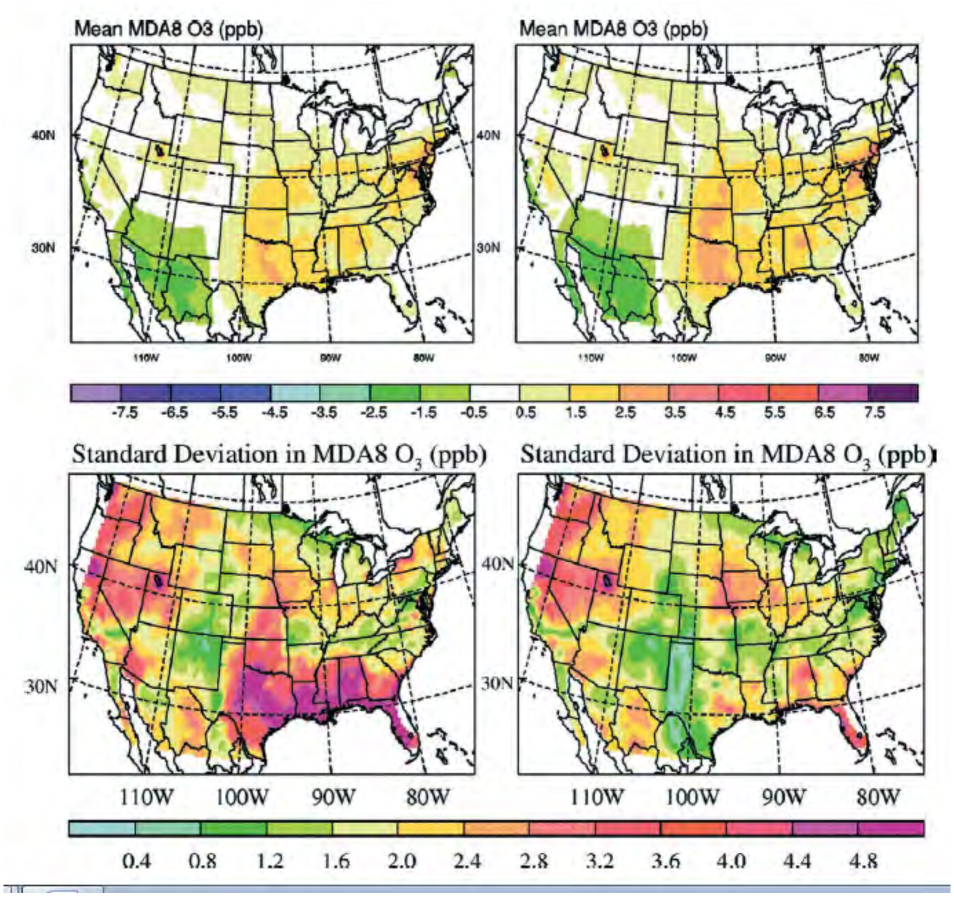


Figure 21-12: Mean (top panels) and standard deviation (bottom panels) in future-minus-present MDA8 summer ozone concentrations across (left-hand panels) all 7 experiments (5 regional and 2 global) and, for comparison purposes (right-hand panels) not including the WSU experiment (which simulated July only conditions). (From Weaver et al. 2009)

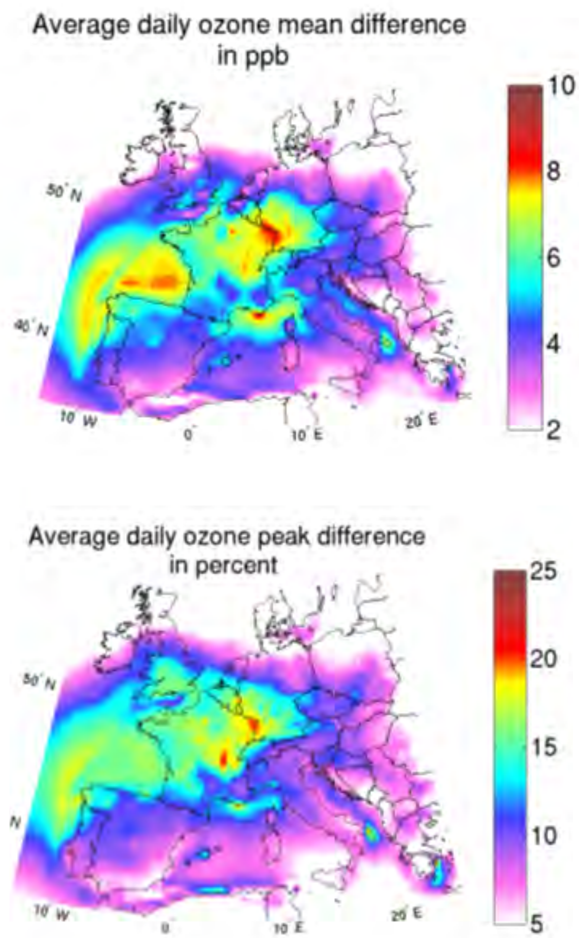


Figure 21-13: Difference in average summer daily ozone mean (left panel) and peak (right panel) concentration over Europe due to climate change, A2 scenario. (From Meleux et al. 2007)

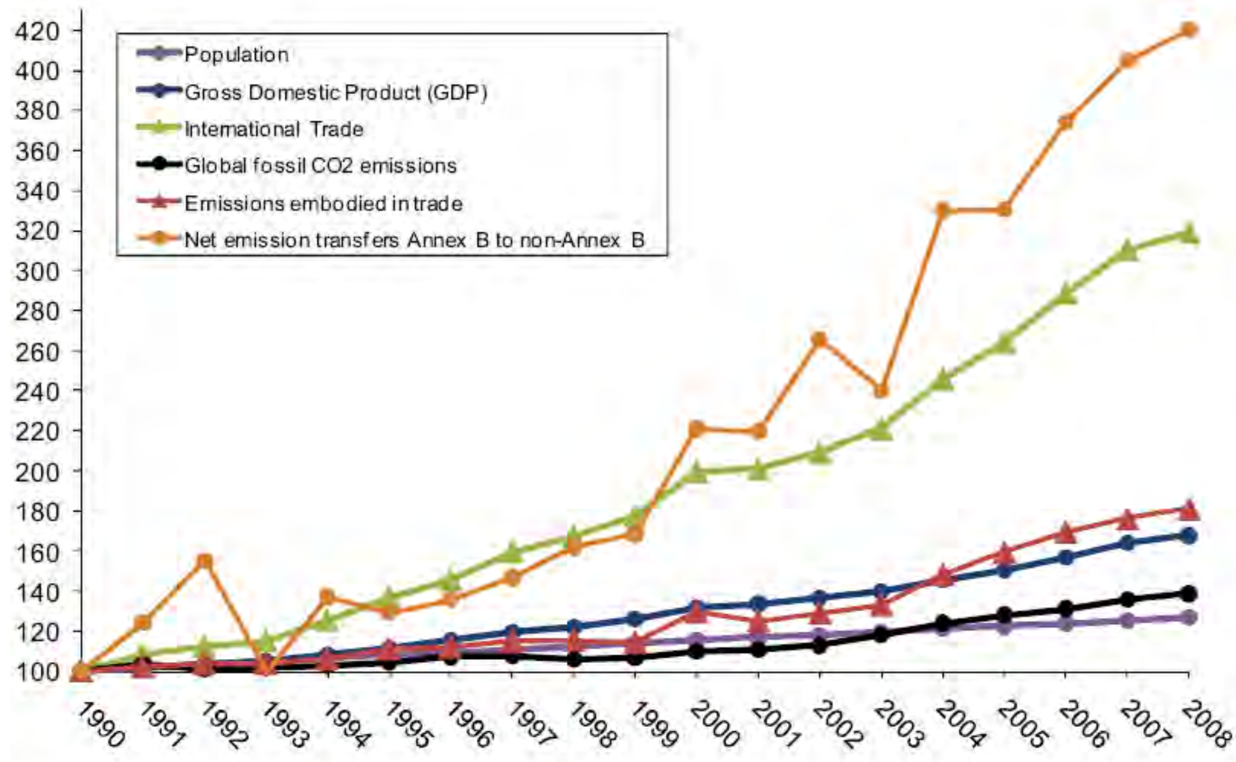
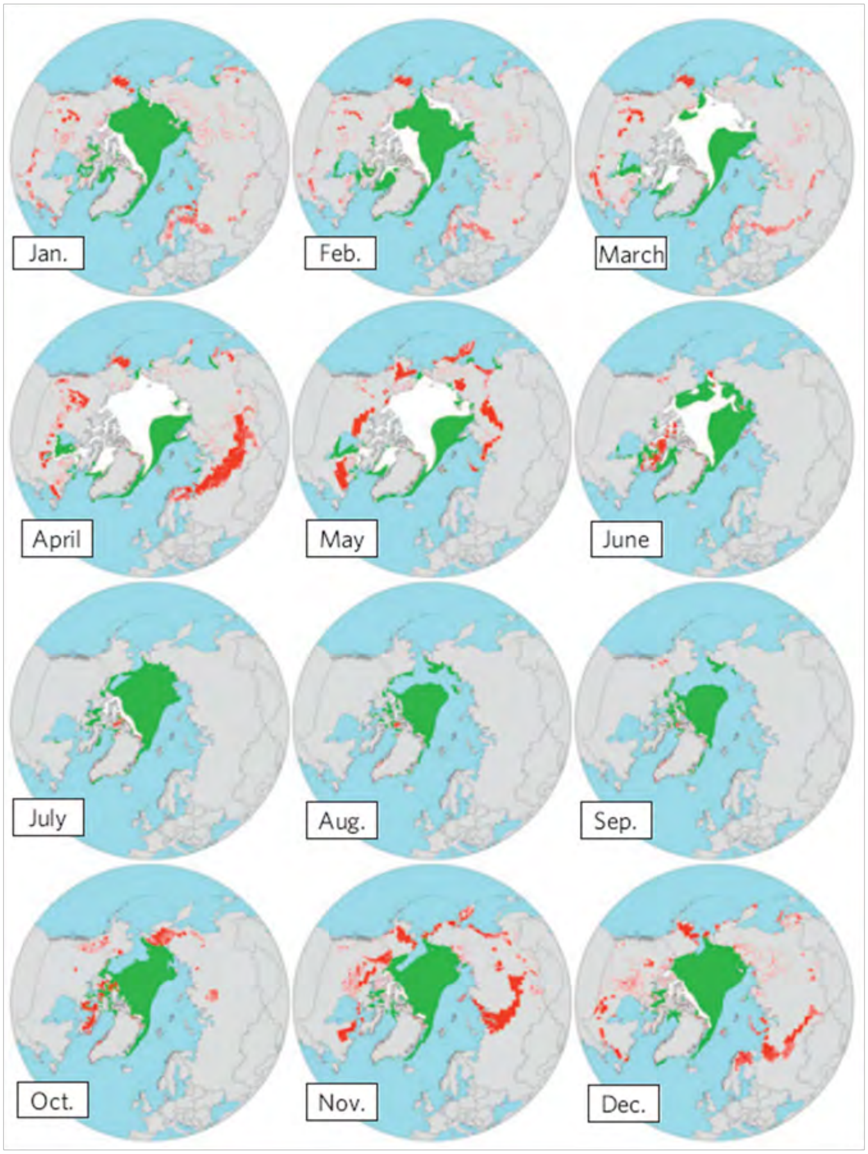
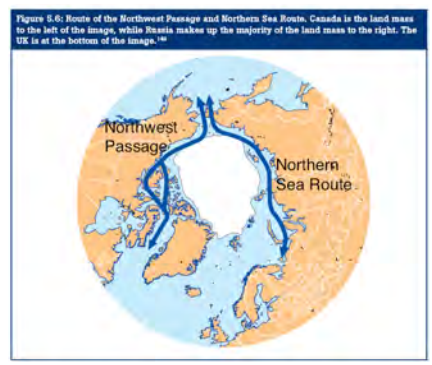


Figure 21-14: Growth rates from 1990-2008 of international trade, its embodied CO_2 emissions and net emissions transfers from Annex B and non-Annex B countries compared to other global macrovariables, all indexed to 1990 (Peters et al., 2011).

(Notes: Screen captured image - Carter)



(a)



(b)

Figure 21-15: (To be reworked) Projected change (a) in accessibility of maritime and land-based transportation by mid-century (2045-2059 relative to 2000-2014) using the Arctic Transport Accessibility Model and CCSM3 climate and sea ice estimates assuming an SRES A1B scenario. Green areas denote new maritime access to Type A vessels (light icebreaker); white areas remain inaccessible. Red delimits areas of lost winter road potential for ground vehicles exceeding 2 metric tonnes (Stephenson et al., 2011). Route (b) of the Northwest Passage and Northern Sea Route (right), which is part of the Northeast Passage (Government Office for Science, 2011).

[Could also add the Arctic Bridge and North Pole routes]

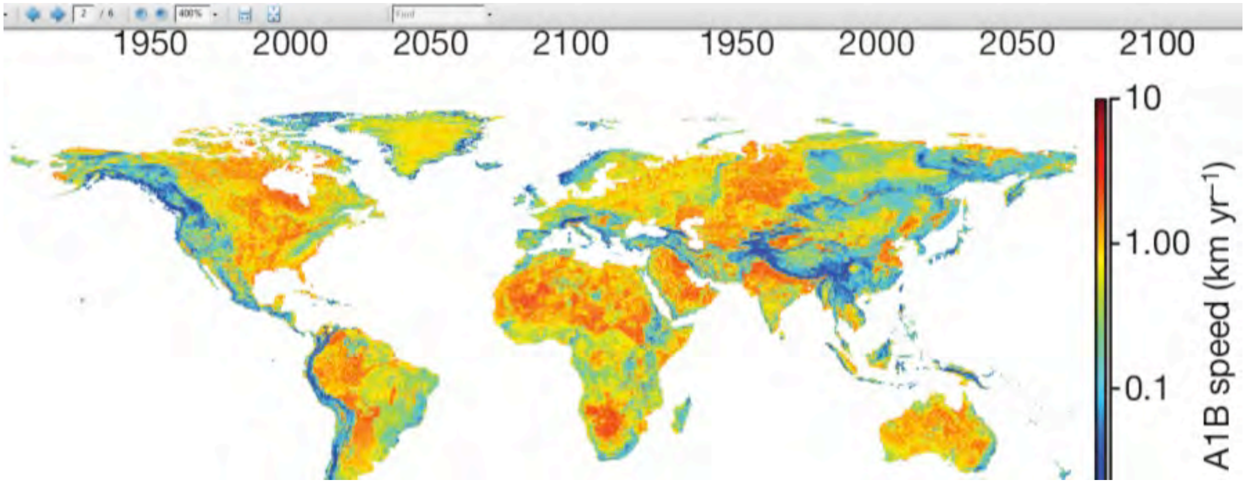


Figure 21-16: The velocity of climate change based on the average of 16 global climate models for an A1B emissions scenario and temporal gradients computed for 2050-2100. (Loarie et al., 2009)

(Notes: Screen captured image - Carter)