Chapter 21. Regional Context

Coordinating Lead Authors
Bruce Hewitson (South Africa), Anthony Janetos (USA)

Lead Authors
Timothy Carter (Finland), Filippo Giorgi (Italy), Richard Jones (UK), Won-Tae Kwon (Republic of Korea), Linda Mearns (USA), Lisa Schipper (Sweden), Marten van Aalst (Netherlands)

Review Editors
Thomas Downing (USA), Phil Duffy (USA)

Contents

Executive Summary

[to be developed]

21.1. Introduction

21.1.1. Purpose of the Chapter

This chapter serves a new role in IPCC assessment reports, and fills two primary purposes in the Working Group II volume. First is bridging part A and B of this report, and second is to contextualize the emerging knowledge and understanding that informs regional issues relating to climate change impacts, adaptation and vulnerability (IAV), including relevant messages from WG I and WG III. The chapter does not an provide exhaustive assessment of regional details, but rather focuses on the emerging new understanding of regional change, and an assessment of the methods and approaches to regional IAV studies.

Bridging part A and B draws on the chapters of part A that address individual sectors and concerns (chapters 2-13), on the processes of adaptation (chapters 14-17), and multisectoral stresses, impacts, vulnerabilities and opportunities (chapters 18-19). Together these provide a strong conceptual framework and assessment of the topical literature. While there has been some exploration of case studies in these chapters, their concepts need context that is specific to the regional summaries that make up Part B, as it is within the regional context that these concepts and frameworks are necessarily applied. This recognizes that IAV issues and opportunities vary substantially around the world, depending on underlying baselines of the state, condition, and demands for goods and services from the natural world, and depending on baselines, development pathways, and social or governance issues in sociopolitical systems.

The second purpose is to identify new or emerging issues and understanding in the underlying science of IAV, with an emphasis on those issues that are particularly important for interpretation within a regional context. Inherent in presenting the major areas where our understanding has changed are both methodological advances in the underlying science (e.g. new capacities for developing regionalized climate scenarios or regionalized depictions of carbon sequestration potential), and the degree to which new regional data have emerged. The chapter will discuss primarily those areas of science in which our understanding has changed since the publication of the IPCC Fourth Assessment (AR4). To this end the chapter draws on the messages from WG I and links into the context of WG III.

In addressing these main foci, the chapter places the bulk of attention on two key sections; the assessment of methods in the regional IAV literature (section 21.3), and new understanding and emerging knowledge on climate change from the physical sciences and mitigation research that have bearing on the assessment of the regional IAV literature.

21.1.2. Sources of Regional Information for IAV

There are three primary sources from which Chapter 21 draws in order to integrate understanding from a wide variety of scientific disciplines in a regional context. These sources approximately map onto material contained in the Working Group II, I and III reports, respectively.

21.1.2.1. Mapping Sectors and Topics into Regional Chapters

The topics addressed in Part A of the Working Group II volume are not all equally important in all regions of the world. Rapidly developing regions, with large increases in urbanization and developing economies face very different socioeconomic contexts than large industrialized economies, with lower completed fertility in human populations, for example. Regions with abundant forest have different inherent sensitivities to a given climate change than regions that are semi-arid. Some of these differences have been explored in AR4 and in the Millennium Ecosystem Assessment. This chapter maps the assessment of sectoral topics into the different regions of the world, issues that are covered in detail in the subsequent chapters of Part B, and are also touched upon with regard to mitigation aspects in the WG III volume.

21.1.2.2. WG1-Type Information

Advances in understanding of the geophysical and biophysical systems must clearly be mapped into a regional spatial context that is necessary to consider for studies in IAV. Of particular importance is the improvement of our understanding of the regional nature of variability and change (both past and projected future) in the physical climate system, as inputs to IAV studies. Just as importantly, though, are the improvements in our understanding of the nature of changes in state and sensitivity of natural resources themselves and their influence on fluxes of material and energy with the coupled climate system – e.g. the regional patterns of changes in forest area and functioning, or improved understanding of the underlying sensitivity of ecosystems to change in the climate system.

21.1.2.3. WG3-Type Information

Just as the scientific communities' understanding of the physical environment has improved on regional scales, so too has the understanding of the regional dimensions of energy systems, mitigation technologies, and socioeconomic pathways. Regional variations in the capacity of the biosphere to sequester carbon, the rates at which technologies diffuse through different socioeconomic systems, or the availability of geological sequestration capacity for carbon dioxide are all examples of where regional contexts can have large implications for mitigation-related sciences.

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 emphasise some of the crucial regional issues to be pursued in Part II of this report.

21.2.1. Decisionmaking Context

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 as set out in the United Nations Framework Convention on Climate Change (UNFCCC). 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.

The 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] (Figure 21-1), and the Non-Annex I Parties, which are mostly developing countries (Table 21-1). Annex I OECD members are further designated as Annex II Parties (Figure 21-1). 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 EIT Parties[1] 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 (Table 21-2). Developing countries eligible to receive official development assistance (ODA) are classified by the OECD according to per capita income (Table 21-3). 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 FOOTNOTE 1 HERE: Members of the Organisation for Economic Co-operation and Development (OECD) in 1992 plus economies in transition (EIT), including the Russian Federation, Baltic States and several Central and Eastern European States.]

[INSERT FOOTNOTE 2 HERE: 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.]

[INSERT FIGURE 21-1 HERE
Figure 21-1: Mapping of the Annex I Parties onto members of the Organisation for Economic Co-operation and Development (OECD), European Union countries (including applicants) and Economies in Transition under the UNFCCC. Revised and updated from (Höhne et al., 2005).]

[INSERT TABLE 21-1 HERE
Table 21-1: The 153 Non-Annex I Parties to the UNFCCC (UNFCCC, 2011).]

[INSERT TABLE 21-2 HERE
Table 21-2: List of Annex B Parties that were signatories to the Kyoto Protocol and their quantified emission limitation or reduction commitments (percentage of base year or period) (UNFCCC, 1998).]

[INSERT TABLE 21-3 HERE
Table 21-3: OECD Development Co-operation Directorate (DCD-DAC) list of countries and territories eligible in 2010 to receive official development assistance (ODA) (OECD, 2011). [Maldives no longer LDC].]

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 Figure 21-2).

[INSERT FIGURE 21-2 HERE
Figure 21-2: The Least Developed Countries (LDCs), Small Island Developing States (SIDS – marked with *) and Landlocked Developing Countries (LLDCs – marked with #). SIDS listed in italics are Non-UN Members / Associate Members of the Regional Commissions. Valid in June 2011 (OHRLLS, 2011).]

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 21-4)
- 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 (Figure 21-1)
- Group of 77 and China[4] (Table 21-5)
- OPEC (Organization of the Petroleum Producing Countries – Table 21-6)[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.

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

[INSERT FOOTNOTE 4 HERE: 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.]

[INSERT FOOTNOTE 5 HERE: OPEC is an international organization of eleven developing countries which 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.]

[INSERT TABLE 21-4 HERE
Table 21-4: Alliance of Small Island States (AOSIS) (AOSIS, 2011).]

[INSERT TABLE 21-5 HERE
Table 21-5: Group of 77 and China (G77, 2011).]

[INSERT TABLE 21-6 HERE
Table 21-6: Organization of the Petroleum Producing Countries (OPEC) (OPEC, 2011).]

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, 2011)) are administered by committees drawn from different regional groupings.

21.2.2. Other Aspects Requiring a Regional Dimension

All of the constellations of countries depicted in the above figures and tables represent political groupings, many of which relate to level of economic development, some to geographical characteristics (small islands and landlocked territories) and others to contiguous regional economic alliances (e.g. African Group, EU) or shared economic interests (e.g. OPEC). Climate change, on the other hand, respects no political boundaries. Climate changes due to anthropogenic and natural forcings can be highly variable from region to region. 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 21-7. 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 information is still required to summarise the processes and trends they depict. Indeed, an atlas is being produced to accompany the Working Group I report, and some examples from that atlas can be expected to find their way into the regional chapters of this volume.
- *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. 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.

_____ END BOX 21-1 HERE _____

[INSERT TABLE 21-7 HERE
Table 21-7: 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.]

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

21.3.1. Decisionmaking Context
21.3.1.1. Policy or Decisionmaking Context
21.3.1.2. Consideration of Adaptation Approaches, Options, Possible Decisions, Adaptive Capacity, Constraints
21.3.1.3. Time Scales of Interest
21.3.1.4. Spatial Scales of Interest
21.3.1.5. Sectors of Particular Interest

[narrative for Sections 21.3.1.1 to 21.3.1.5 to be developed]

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. Clearly there are linkages between each area, for example in assessing climate change vulnerability or how to adapt to climate change one needs to have knowledge of what impacts are likely to be. This does not imply that the information requirements in each case are the same as these assessments will be applied to systems which generally comprise interacting physical and human components both of which are likely to be influenced by 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. Thus here information is required not only on climate but on other physical aspects of the system as well as social and economic factors and this will generally be the case.

The rest of this section is devoted to recent findings and advances in the development and treatment of baseline information relevant to climate change impacts, vulnerability and adaptation assessments. First, climate baselines relevant to the study of climate change impacts are addressed followed by the non-climatic baseline information which additionally is relevant to the study of climate change vulnerability and adaptation.

Climate baselines

An understanding that the quality and the resolution of the climate baseline chosen for an impacts study can significantly affect the findings of the study (e.g. Arnell et al., 2003) has motivated further study of this issue. For example, in a study of impacts of climate change on UK river flow 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 but that a greater range of projected changes resulted when using high time-resolution (daily) information than when using monthly changes (Figure 21-3). This underscores 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 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.]

The recognition that a good description of the baseline climate (which will implicitly include information on climate variability on timescales of days to decades) is important for developing the baseline state of a system sensitive to climate 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 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 the 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).

[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).]

An important element of 20CR is that 56 reconstructions of the 140-year global weather evolution have been calculated from which the error in either a single or the ensemble mean reconstruction can be estimated. This issue of calculating error estimates/using multiple estimates of the observed climate has received much more attention recently following the focus on this in respect of establishing millennial-scale global and hemispheric temperature records (AR4-WG1) and the sensitivity of estimated baselines in impacts systems to the estimate of observed climate used to construct the impact baseline (Arnell et al., 2003). The importance of the quality of the observed impact baseline depends on the context in which it is being used. When studying the range of yields from an agricultural system that would be expected from historical climate variability it is important that a model of the system is able to reproduce the observed sequences of yields with observed weather inputs for the same period (e.g. Challinor et al. (2004)). A somewhat different example is where high quality observed data are used to demonstrate the ability of the impacts model to simulate an accurate baseline, in order to establish confidence in the impacts model, and then use this model with less accurate climate model-derived baselines which are then compared with results when using climate-model derived futures (e.g. Bell et al., 2011). In this case the impacts model is being used to translate plausible timeseries of current climate variables to derive realistic (though not necessarily accurate) baselines. Ranges of climate change impacts calculated from these baselines and the response of the system to sets of future climate variables can then be considered a plausible set of outcomes given the initial validation of the impacts model.

In the examples given above, high resolution climate timeseries, either observed or simulated, were used in the calculation of impacts baselines and responses. The recent reanalyses may provide globally complete and temporally detailed reconstructions of the climate of the recent past, and the ability to derive estimates of the error in the reconstructions, but they generally lack the resolution to be able to capture the many fine spatial details of weather events that are important when modeling the response of systems sensitive to climate. In this case higher resolution downscaling can be used in conjunction with the reanalyses to add these fine-scale details (see e.g. Maraun et al., 2010). 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) where the initial experiment is to downscale ERA-Interim over all land regions (ref to CORDEX overview paper which will probably be C. Jones et al., 2011).

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 was required in the impacts model and coarse resolution GCM-based projections were available but with the widespread availability of high resolution projections 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 taking account of the full detail of projected climate change the perturbations applied should account for changes in all relevant aspects of climate variability.

[Notes: Available studies on this issue will be assessed and relevant conclusions drawn in subsequent drafts]

Non-climatic baselines

In assessing climate change vulnerability account must be taken of the system's ability to cope with the impact of short-term climatic or weather events and its ability to adapt to long-term climate changes. Thus an understanding of the climate change adaptation potential of a system is important in studying its vulnerability. As noted at the start of this section, climate sensitive systems are generally influenced by other, non-climatic, factors. Thus in order 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. The very wide and diverse range of systems that are sensitive to climate clearly are influenced by many and different combinations of non-climatic factors. Generally the different climate impacts study areas, e.g. agriculture, water resources, ecosystems, health, are sensitive to specific sets of non-climatic factors but these can be strongly influenced by the nature of the system (e.g. rain-fed as opposed to irrigated agriculture) as well as the socio-economic and political situation of the region in which the system functions (e.g. disease prevention in Europe as opposed to Africa). It is these main areas of (non-climatic) influence on which information is required to assess vulnerability. They have been classified in previous assessments under three main categories (e.g., Carter et al., 2007): other environmental factors (e.g., current trends in local sea-level change, atmospheric composition), land use and land cover, and socio-economic conditions. The third of these can further be sub-divided into factors such as demography, level of socio-economic and educational development, political/governance and technology.

As with climate baselines, much information is available in all these areas and in many cases there is already significant work that has been done in collecting information on and assessing the vulnerability of human and natural systems to these factors. Local and national governments and international agencies have been collecting data on the human-related factors for many decades and similarly information on technological developments is widely available. The physical environment in many areas has been well-studied and detailed records are available though, much like with climate observations, there are still areas of the world which are less well-observed. In this area, rescuing and/or making available old records of the physical environment is of significant value as is making new or more detailed observations.

As the importance of the non-climatic baseline information being assessed here is how it influences the capacity of systems to adapt to climate change (which, as explained above, is also an element of assessing the systems vulnerability to climate change), it is the relationship between the other factors and the potential impact of climate change that is key. Generally climate has been viewed as a factor which varies a know 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 vulnerability and adaptation to climate change in a system is defining the non-climatic information required. Given the diversity of climate-sensitive systems as explained above, it is not possible to assess 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 the information 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.

A simple example which demonstrates the issues with establishing non-climatic baselines, in this case in the physical environment, is the study of climate change impacts on river flow. For the River Thames in the UK there is no long-term trend in annual maximum flows over a 126 year series (Marsh 2004). This is despite increases in temperature and a major change in the seasonal partitioning of rainfall over the Thames basin (in the 19th century summer rainfall was on average greater than for the winter) 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, for example, increases in channel capacity of 30% over 70 years leading to fewer floods in the lower Thames. In this case a detailed investigation was able to establish the important properties of the physical environment relevant to an assessment of the vulnerability of the Thames to flooding.

A second example involves a study of the potential for adaptation in response to projected climate change impacts on crop yields (Challinor et al., 2009). The results of the projected changes indicated crops with increased thermal time requirement were required and the study of Badigannavar et al. (2002) detailed fields studies suggesting that these were available in the current germplasm. In this case, information on technology baselines relevant to the adaptation study being investigated was available.

[Notes: More examples and relevant references on these issues will be presented and assessed in subsequent drafts]

21.3.3. Characterizing the Future

21.3.3.1. Development of Scenarios and Projections

[Notes: This section will cover new/emerging issues in climate and other scenario information. Will particularly discuss spatial/temporal issues in both, use of multiple scenario elements, and new RCP scenario development process. Depending on how RCPs treated elsewhere, this section will also something about RCPs.]

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).

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), and over South America (CLARIS) and these are now being used in impacts and adaptation studies (e.g., Miles et al., 2010, Morse et al., 2009). 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). 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.

Use of multiple scenario elements

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. [Need a few more recent examples here?].

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 single 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 stabilization assumptions, which were missing from the SRES set. More information on these scenarios may be found in WG3 (maybe?) Report, and WG1, Chapter 12, section 12.3.1.3. However, due to the time lags that still exists 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. Variables/Issues of Interest – Multiple Stressors

[Notes: This section will cover variables of interest, also other major projection components that can act as 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). 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, structures of governance, among others. 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 water shed 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.
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

[Notes: Assume by application we mean application to impacts analysis and decision making. Several major examples of applications will be discussed here.]

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 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 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.

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 scenario 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 Quality and Uncertainty

21.3.4.1. Evaluating Variability

[Notes: This section should discuss both models of variability important for impacts/adaptation assessments and uncertainty resulting from internal variability (per email exchange with Hewitson, However, I think the internal variability section could also go with the other aspects of uncertainty discussed in section 21.4.3)]

Internal variability (Cross reference to section 12.2.1.2 of WG1 Chapter 12)

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). Natural 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, how many in CMIP5?). However, some recent research has explored larger numbers of ensemble members (e.g., Deser et al., 2010) and have thus come up with improved measures of natural variability.

Evaluating Modes of Variability important for impacts/adaptation (Cross Reference to Chapter 11 of WG1)

[PLACEHOLDER waiting for additional CMIP5 information to emerge]

There are numerous modes of climate variability that can be important form a climate impacts perspective. These include such phenomenon ad the El Nino/Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Southern Annular Mode (SAM), and the IPO (Interdecadal Pacific Oscillation). A complete discussion of all these modes is presented in Chapter 14 of WG1. It is understood that these modes will continue to exist with ghg-induced climate change, but they may change in ways that would be important for impacts research. For example, changes in the frequency and intensity of ENSO could have substantial effects on the frequency of droughts in eastern Australia, and various rainfall patterns in the US, also related both to flooding and drought, as could changes in the NAO have regarding winter weather over northern Europe. Similarly changes in the IOD could influence the frequency and intensity of droughts in Indonesia, and floods in East Africa. We review only a few of the major modes of variability here. The reader is referred to Chapter 14 in WG1 for more complete coverage of all models of variability.

ENSO is certainly the mode of variability that has received the most attention from a climate impacts point of view. Its effects on human and natural resource systems has been very well documented (ref.), and forecasting of El Nino behavior in a seasonal forecast mode has played an important role in the use of seasonal forecasts for providing warning of difficult conditions for impacts worldwide (Easterling et al., 2007, NAS study). [So far we only have further analysis of CMIP3 studies for this section – will be supplemented with CMIP5 results.] Research over the past three or four years have underscored the complexity of the ENSO system and provided some explanation for this complexity, 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 do 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).

21.3.4.2. Limitations to Knowledge

[Notes: This section should discuss both the general progress in what is modeled in climate models, as well as what is still left out, etc.]

There are numerous limitations to our knowledge about future climate change, and these limitations lead to a host of uncertainties related to our limited ability to predict the future both regarding the response of the physical climate system to future forcings and the future of all aspects of human life that will influence the production of emissions of greenhouse gases and aerosols. Firstly, 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), 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 import 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).

Uncertainties regarding projections of population, GDP, technology remain very large, and there is little likelihood of reducing these types of uncertainties beyond a decade into the future. [Needs a bit more here?].

21.3.4.3. Management of Contradictions

[Notes: This section will cover methods for evaluating contradictory information about future climate, such as differences in climate change projections from global climate models, regional models, and statistical downscaling. It also should consider contradictions of these various modeling results with trends in observations. Note the Hewitson article on contradictions between stat downscaling and climate model results over Africa (only about to be submitted)]

Climate change projections from global climate models and any subsequent downscaling generally disagree on the amount (e.g. for temperature and sea-level) and in some case the sign (e.g. for precipitation and wind) of 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.

Other approaches that have been followed include relating the degree of bias in climate model simulations and the degree of climate change (e.g., Hall and Qu, 2006; Smith and Chandler, 2010). Through these kind of careful climate process analyses the relative plausibility of a particular climate model's response to forcing could be determined.

In many cases, the situation is different from the main example given above of having a clear understanding of the drivers of observed changes and all models reproducing these and both the direction and, to a reasonable degree of accuracy, the magnitude of the change. Several other possibilities are listed below along with examples or suggestions of how these can be dealt with.

- 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 probably implies that other processes are important and thus research is required to identify these and ensure that they are correctly represented in the models.
- 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 are all for 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.
- More often, future projections may go in opposite directions to each other and none of these can be excluded on the basis of our physical understanding of the drivers of these changes. An example here is provided by McSweeney et al., (2011) who analysed an ensemble of GCMs over south-east Asia and found that all models simulated the important monsoon processes and rainfall well but they projected a range of changes in monsoon precipitation, including both positive and negative, and different patterns of change. In the absence of available information on observed trends in precipitation or more detailed process understanding they advised the use of subset of the ensemble to characterise the range of projected futures

as none of these outcomes could be excluded and there was insufficient information to provide more definitive predictions. Another approach can be using a Bayesian probabilistic framework to combine the contradictory information such as differences direction of change in precipitation in a global climate model (e.g. Tebaldi and Knutti, 2007) 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).

- Finally, it is important to differentiate between the case of where the lack of understanding is due to research having been done but no clear answer being found compared to where the results have not been scrutinized due to lack of research effort. In the case described in (1), significant research has been undertaken on the problem and thus the presence of a contradiction in the projected changes implies that there is a major issue to be resolved and currently significant uncertainty remains for the future in this region. However, in the case described in (3), there has been much less effort in analysing trends and projected changes in south-east Asia and thus there is the possibility that the current contradictory projections could be reconciled with some targeted research.

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 which 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 derived mostly from a wide range of station and satellite observation products and from global model simulations participating in the CMIP3 program. 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

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.

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 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 southeastern 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 (Figure 21-5). 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. Finally, 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.

[INSERT FIGURE 21-5 HERE
Figure 21-5: The percentage of seasons in the CMIP3 AIB ensemble for which the surface air temperature exceeds the warmest season of the 1980-199 period. The early 21st century period is 2010-2039, the mid 21st century period is 2040-2069, the late 21st century period is 2070-2099. (From Diffenbaugh 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 21-6). 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 summer (Giorgi and Lionello 2008), and central/northern Europe much warmer and wetter in winter (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 21-6 HERE
Figure 21-6: 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 Europen 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 21-7). 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). These results indicate that uncertainties in projections of the hydrologic cycle of Africa remain very high and need large ensembles in order to be fully characterized.

[INSERT FIGURE 21-7 HERE
Figure 21-7: 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. [Notes: materials not citable yet, should be by FOD]

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.

[PLACEHOLDER for additional material yet to emerge from CMIP5 and CORDEX]

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

The results published in the AR4, regarding precipitation change still hold on the broad continental scale, with precipitation increases dominating the northern third of the continent and drying in the southern third. 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). Changes in precipitation in other regions of North America remain less clear, for example in the US Southeast, where there is little model agreement. Summer precipitation east of the Rockies is also unclear, with little model agreement. This may be due to the model weaknesses in simulating convection (Ruiz-Barradas and Nigam, 2006, 2010).

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 and higher resolution time global time slices. The North American Regional Climate Change Assessment Program (NARCCAP) has been the major 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; 2011). 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 kms, 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 21-8). 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. This suggests a distinct lack of robustness in the projected precipitation changes in summer.

[INSERT FIGURE 21-8 HERE
Figure 21-8: 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. Liang et al. (2011) has produced multiple high resolution scenarios over the United States using the RCM CWRF for different combinations of SRES scenarios and nesting GCMs, but the time periods are relatively short (ten years of current and ten years of future). 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). For the Pacific Northwest a perturbed physics experiment is underway using the HadRM3 (ref?). Very few PPEs have been constructed using RCMs.

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).

[PLACEHOLDER: For CORDEX, simulations with North America are planned].

Asia

GCMs tend to produce a consistent pattern of increased monsoon precipitation over both the East and South Asia regions, 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.

[PLACE HOLDER: Small islands]

[PLACE HOLDER: For all areas there will be an update based on CMIP5 and CORDEX results]

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.

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 meridional overturning circulation (MOC).

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 MOC of the Atlantic Ocean 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.

New understanding and emerging knowledge

Better understanding of ice flow dynamics was achieved along with better modeling of these *processes* (Notes: Refs to be added from WG1 Relevant chapters when available), 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 sea level rise were extended to 2009 and the new estimates of the different contributions are significantly different from the AR4. More specifically, the estimated sum of all contributions is closer to the observed values than in the AR4, although still being lower: 1.33 +/- 0.35 vs. 1.66 +/- 0.18 for 1961-2008, 2.7+/- xx vs. 3.3 +/- 0.4 for 1993-2009. This adds confidence to the methods used to calculate the components estimates.

New projections of sea level rise by 2100 based on the CMIP3 data have been produced (Notes: REFS to be added from WGI relevant Chapters when available) using both physical models for the different contributions and semiempirical models. Compared to the range in the AR4 the upper end of the new range of estimates is much higher, well exceeding 1 m for the high end scenarios.

[PLACE HOLDER: New estimates based on the CMIP5 climate ensemble will be produced – the upper end of the Sea level rise range will very likely increase.]

Global maps of sea level rise were produced based on the AR4 climate ensemble using different methods (Katsman et al. 2011). These 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 (e.g. change in wind stress).

[PLACE HOLDER: More robust maps are likely to be produced from the CMIP5 ensemble and possibly from RCMs (e.g. for the Mediterranean)]

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 also results in increase of storm surges.

[PLACE HOLDER: Update on tropical storms and hurricanes]

[PLACE HOLDER: Update on projections of MOC from CMIP5]

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).

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.

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 21-9) 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.

[INSERT FIGURE 21-9 HERE
Figure 21-9: 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).]

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 21-10).

[INSERT FIGURE 21-10 HERE
Figure 21-10: 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).]

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).

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.

New understanding and emerging knowledge

The assessment of Chapter 4 of the WGI report shows that, new data and improved analysis techniques since the AR4 have confirmed with greater confidence that both the Greenland and Antarctic Ice sheets have been loosing mass in the last decades. Among these new data are the GRACE satellite ones, which have allowed more accurate assessments of the ice sheet mass balance. The mass loss of the Greenland ice sheet has been increasing in the last 20 years, and data indicate also an increased mass loss from Antarctica, although with a less distinct signal (see Tables 4.2 and 4.3 of the WGI Chapter 4.). Globally, glaciers and ice caps are in a receding phase (Table 4.7 WGI Chapter 4), providing a significant contribution to global sea level rise. New data, both in situ and from satellite confirm a decrease of spring snow cover over land (Notes: link to WGI figure/table/refs). Summer sea ice extent has also continued to decrease (Notes: link to WGI figure/table.refs.).

[PLACEHOLDER: More on cryosphere (e.g. also including permafrost, frozen ground etc.) when WGI Chpater 4 is more advanced and results from new projections are available.]

21.4.2. Mitigation Research

Most of the research assessed in this chapter is, of course, related to impacts, adaptation, and vulnerability. But a complete understanding of regional context also includes consideration of both the current state and potential for mitigation of greenhouse gas emissions – either through 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 (need the reference to the major intercomparision of DGVM's), 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, in press).

More recent literature begins to do 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. (in press) Thomson et al. (2010, in press) Wise et al. (2009) present a series of scenarios of land-use and land-cover change that have focused on how those changes interact with 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 the 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 in press, 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 same overall demand. This result is due to the fact that the competition for arable land forces agriculture onto less suitable lands and lowers its 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 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

Integrated assessment models have demonstrated that the availability of energy technologies 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 (will need to get more references here), 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) summarized a literature showing that there are common determinants of mitigation capacity, sustainable development, and resilience/adaptive capacity.

But there has been very little research on scenarios that develop aspects of both mitigation and adaptation capacity jointly. 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 (in press) 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. (need to find out if the Kriegler et al paper has also been accepted and also reference it).

21.4.3. Multiple Lines of Evidence, Uncertainties, and Probabilities

[PLACEHOLDER: pending further material from WG1 other papers in preparation]

21.5. Regional Distributions of Key Issues

[Notes: this section will be a description of regional differences/commonalities (with appropriate key figures and tables for illustration – a very short, descriptive section, not an exhaustive synthesis. This section needs to draw on the regional chapters in order to bring out the key issues and assess what is the most striking – including similarities and differences; It is too soon to obtain this information, and hence for now this section focus' on identifying the structure of these various sub-sections.]

21.5.1. Vulnerabilities

[Notes: Vulnerability is used by the IPCC in a sort of strange way. In AR4, it is sometimes hard to distinguish from impacts – case in point: that is why it is even possible to use the noun 'vulnerabilities' – however, SREX Chapter 2 uses vulnerability as an adjective, to refer to the outcome of the mainly socially constructed conditions that make people exposed and sensitive to natural hazards and environmental change. This means that, while climate change can certainly make people more exposed and sensitive to hazards and environmental change, their vulnerability is primarily driven by social, institutional, economic, cultural and political characteristics such as gender, age, employment status/livelihood, political affiliation, etc. etc. This section will somehow have to include both – the traditional IPCC 'vulnerabilities' and also the more development-context defined drivers of vulnerability. Included here would be issues like migration, economic crises/debt, HIV/AIDS and other health issues, political instability, environmental degradation, which will affect different regions differently, and be comparatively more relevant for making people in the different regions more vulnerable to certain kinds of natural hazards or environmental change.]

Africa
Asia
Australasia
Europe
North America
Central + South America
Polar Regions
Small Islands
Open Oceans

21.5.2. Impacts

Africa
Asia
Australasia
Europe
North America
Central + South America
Polar Regions
Small Islands
Open Oceans

21.5.3. Adaptation Approaches

Africa
Asia
Australasia
Europe
North America
Central + South America
Polar Regions
Small Islands
Open Oceans

21.5.4. Sectoral Issues

Africa
Asia
Australasia
Europe
North America
Central + South America
Polar Regions
Small Islands
Open Oceans

21.5.5. Hot Spots – Defined by Underlying Vulnerabilities and/or Physical Sensitivities

[forthcoming]

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.

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 21-11), and most developed countries have increased their consumption-based emissions faster than their domestic (territorial) emissions (Peters *et al*., 2011).

[INSERT FIGURE 21-11 HERE
Figure 21-11: 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 include:

- Severe impacts of recent food price hikes in many developing countries (including food riots and increased incidence of child malnutrition) 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 (bizarrely, an outcome of climate policy) and market speculation (Ziervogel and Ericksen, 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.
- 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. 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). 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 21-12).

[INSERT FIGURE 21-12 HERE
Figure 21-12: Projected change 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).]

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 and Latin America by emerging economies such as India, China and South Korea. While there is clearly a profit motive in some 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.

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, 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% and a sharp rise in the monthly price of both thermal coal and coking coal between November 2010 and January 2011. 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 0.8% in the preceding three-month period (Financial Times, 2011).

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. 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). 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 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 and the migrants themselves are likely to be highly 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). Thus projecting future climate-related migration remains a challenging research topic. 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).

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. 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 21-13). 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 21-13 HERE
Figure 21-13: 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. 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.

21.7. Knowledge Gaps and Research Needs

[PLACEHOLDER: pending further chapter developments]

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Table 21-1: The 153 Non-Annex I Parties to the UNFCCC (UNFCCC, 2011).

Afghanistan
Albania **
Algeria
Angola
Antigua and Barbuda
Argentina
Armenia **
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belize
Benin
Bhutan
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Brunei Darussalam
Burkina Faso
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
Chile
China
Colombia
Comoros
Congo
Cook Islands
Costa Rica
Cuba
Cyprus
Côte d'Ivoire
Democratic People's Republic of Korea
Democratic Republic of the Congo
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Ethiopia
Fiji
Gabon
Gambia
Georgia
Ghana
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
India
Indonesia
Iran (Islamic Republic of)
Iraq
Israel
Jamaica
Jordan
Kazakhstan **
Kenya
Kiribati
Kuwait
Kyrgyzstan
Lao People's Democratic Republic
Lebanon
Lesotho
Liberia
Libyan Arab Jamahiriya
Madagascar
Malawi
Malaysia
Maldives
Mali
Marshall Islands
Mauritania
Mauritius
Mexico
Micronesia (Federated States of)
Mongolia
Montenegro
Morocco
Mozambique
Myanmar
Namibia
Nauru
Nepal
Nicaragua
Niger
Nigeria
Niue
Oman
Pakistan
Palau
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Qatar
Republic of Korea
Republic of Moldova **
Rwanda
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Samoa
San Marino
Sao Tome and Principe
Saudi Arabia
Senegal
Serbia
Seychelles
Sierra Leone
Singapore
Solomon Islands
Somalia
South Africa
Sri Lanka
Sudan
Suriname
Swaziland
Syrian Arab Republic
Tajikistan
Thailand
The former Yugoslav Republic of Macedonia
Timor-Leste
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkmenistan **
Tuvalu
Uganda
United Arab Emirates
United Republic of Tanzania
Uruguay
Uzbekistan **
Vanuatu
Venezuela (Bolivarian Republic of)
Viet Nam
Yemen
Zambia
Zimbabwe
Panama

** Party for which there is a specific procedural decision concerning their status
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Table 21-2: List of Annex B Parties that were signatories to the Kyoto Protocol and their quantified emission limitation or reduction commitments (percentage of base year or period) (UNFCCC, 1998).

Party	**Limitation or reduction (% base)**
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

* Countries that are undergoing the process of transition to a market economy

Table 21-3: OECD Development Co-operation Directorate (DCD-DAC) list of countries and territories eligible in 2010 to receive official development assistance (ODA). Source:(OECD, 2011). [Maldives no longer LDC]

(Notes: Screen captured image – Carter, 14 March 2011)

Least Developed Countries	Other Low Income Countries (per capita GNI < $935 in 2007)	Lower Middle Income Countries and Territories (per capita GNI $936-$3 705 in 2007)	Upper Middle Income Countries and Territories (per capita GNI $3 706-$11 455 in 2007)
Afghanistan	Côte d'Ivoire	Albania	*Anguilla
Angola	Ghana	Algeria	Antigua and Barbuda[1]
Bangladesh	Kenya	Armenia	Argentina
Benin	Korea, Dem. Rep.	Azerbaijan	Barbados[2]
Bhutan	Kyrgyz Rep.	Bolivia	Belarus
Burkina Faso	Nigeria	Bosnia and Herzegovina	Belize
Burundi	Pakistan	Cameroon	Botswana
Cambodia	Papua New Guinea	Cape Verde	Brazil
Central African Rep.	Tajikistan	China	Chile
Chad	Uzbekistan	Colombia	Cook Islands
Comoros	Viet Nam	Congo, Rep.	Costa Rica
Congo, Dem. Rep.	Zimbabwe	Dominican Republic	Croatia
Djibouti		Ecuador	Cuba
Equatorial Guinea		Egypt	Dominica
Eritrea		El Salvador	Fiji
Ethiopia		Former Yugoslav Republic of Macedonia	Gabon
Gambia		Georgia	Grenada
Guinea		Guatemala	Jamaica
Guinea-Bissau		Guyana	Kazakhstan
Haiti		Honduras	Lebanon
Kiribati		India	Libya
Laos		Indonesia	Malaysia
Lesotho		Iran	Mauritius
Liberia		Iraq	*Mayotte
Madagascar		Jordan	Mexico
Malawi		Kosovo[3]	Montenegro
Maldives		Marshall Islands	*Montserrat
Mali		Micronesia, Federated States	Nauru
Mauritania		Moldova	Oman[1]
Mozambique		Mongolia	Palau
Myanmar		Morocco	Panama
Nepal		Namibia	Serbia
Niger		Nicaragua	Seychelles
Rwanda		Niue	South Africa
Samoa		Palestinian Administered Areas	*St. Helena
São Tomé and Principe		Paraguay	St. Kitts-Nevis
Senegal		Peru	St. Lucia
Sierra Leone		Philippines	St. Vincent and Grenadines
Solomon Islands		Sri Lanka	Suriname
Somalia		Swaziland	Trinidad and Tobago[2]
Sudan		Syria	Turkey
Tanzania		Thailand	Uruguay
Timor-Leste		*Tokelau	Venezuela
Togo		Tonga	
Tuvalu		Tunisia	
Uganda		Turkmenistan	
Vanuatu		Ukraine	
Yemen		*Wallis and Futuna	
Zambia			

*Territory.

(1) Antigua & Barbuda and Oman exceeded the high income country threshold in 2007. In accordance with the DAC rules for revision of this List, both will graduate from the List in 2011 if they remain high income countries until 2010.

(2) Barbados and Trinidad & Tobago exceeded the high income country threshold in 2006 and 2007. In accordance with the DAC rules for revision of this List, both will graduate from the List in 2011 if they remain high income countries until 2010.

(3) This does not imply any legal position of the OECD regarding Kosovo's status.

Table 21-4: Alliance of Small Island States (AOSIS) (AOSIS, 2011).

Antigua and Barbuda
Bahamas
Barbados
Belize
Cape Verde
Comoros
Cook Islands
Cuba
Cyprus
Dominica
Fiji
Federated States of Micronesia
Grenada
Guinea-Bissau
Guyana
Haiti
Jamaica
Kiribati
Maldives
Malta
Marshall Islands
Mauritius
Nauru
Niue
Palau
Papua New Guinea
Samoa
Singapore
Seychelles
Sao Tome and Principe
Solomon Islands
St. Kitts and Nevis
St. Lucia
St. Vincent and the Grenadines
Suriname
Tonga
Trinidad and Tobago
Tuvalu
Vanuatu

Observer status: American Samoa, Guam, Netherlands Antilles, U.S. Virgin Islands
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Table 21-5: Group of 77 and China (G77, 2011).

Afghanistan
Algeria
Angola
Antigua and Barbuda
Argentina
Bahamas
Bahrain
Bangladesh
Barbados
Belize
Benin
Bhutan
Bolivia (Plurinational State of)
Bosnia and Herzegovina
Botswana
Brazil
Brunei Darussalam
Burkina Faso
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
Chile
China
Colombia
Comoros
Congo
Costa Rica
Côte d'Ivoire
Cuba
Democratic People's Republic of Korea
Democratic Republic of the Congo
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Ethiopia
Fiji
Gabon
Gambia
Ghana
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
India
Indonesia
Iran (Islamic Republic of)
Iraq
Jamaica
Jordan
Kenya
Kuwait
Lao People's Democratic Republic
Lebanon
Lesotho
Liberia
Libyan Arab Jamahiriya
Madagascar
Malawi
Malaysia
Maldives
Mali
Marshall Islands
Mauritania
Mauritius
Micronesia (Federated States of)
Mongolia
Morocco
Mozambique
Myanmar
Namibia
Nepal
Nicaragua
Niger
Nigeria
Oman
Pakistan
Palestine
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Qatar
Rwanda
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Samoa
Sao Tome and Principe
Saudi Arabia
Senegal
Seychelles
Sierra Leone
Singapore
Solomon Islands
Somalia
South Africa
Sri Lanka
Sudan
Suriname
Swaziland
Syrian Arab Republic
Tajikistan
Thailand
Timor-Leste
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkmenistan
Uganda
United Arab Emirates
United Republic of Tanzania
Uruguay
Vanuatu
Venezuela (Bolivarian Republic of)
Viet Nam
Yemen
Zambia
Zimbabwe

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Table 21-6: Organization of the Petroleum Producing Countries (OPEC) (OPEC, 2011).

Algeria	Libya
Angola	Nigeria
Ecuador	Qatar
Iran	Saudi Arabia
Iraq	United Arab Emirates
Kuwait	Venezuela

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Table 21-7: 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 (Figure B1.1)
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 (Figure B1.2). 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 (Figure B1.3); 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 (Figure B1.4)
		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 (e.g. see Figure B1.5 for Africa); Example vulnerability maps at sub-national scale and globally by country.
		Mitigation: 17 global economic regions for GDP (Figure B1.6); 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 (e.g. Figure B1.7),
***SR**: Renewables* [23]	2011	To be completed
***SR**: Extremes* [24]	2011	To be completed

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 in press); 24. IPCC (2011 in prep)

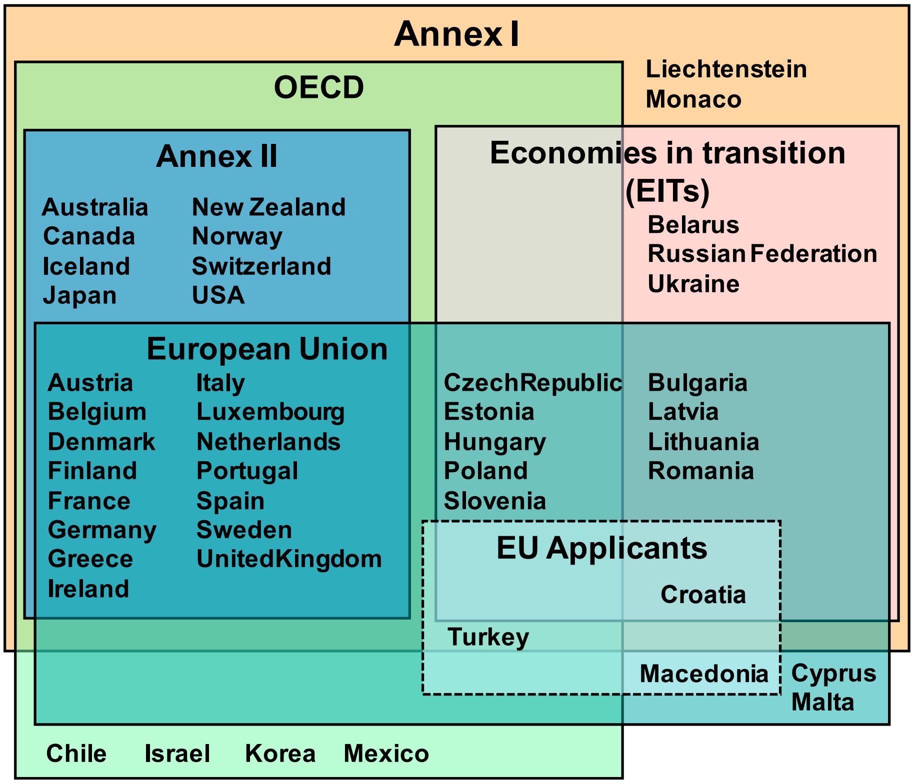
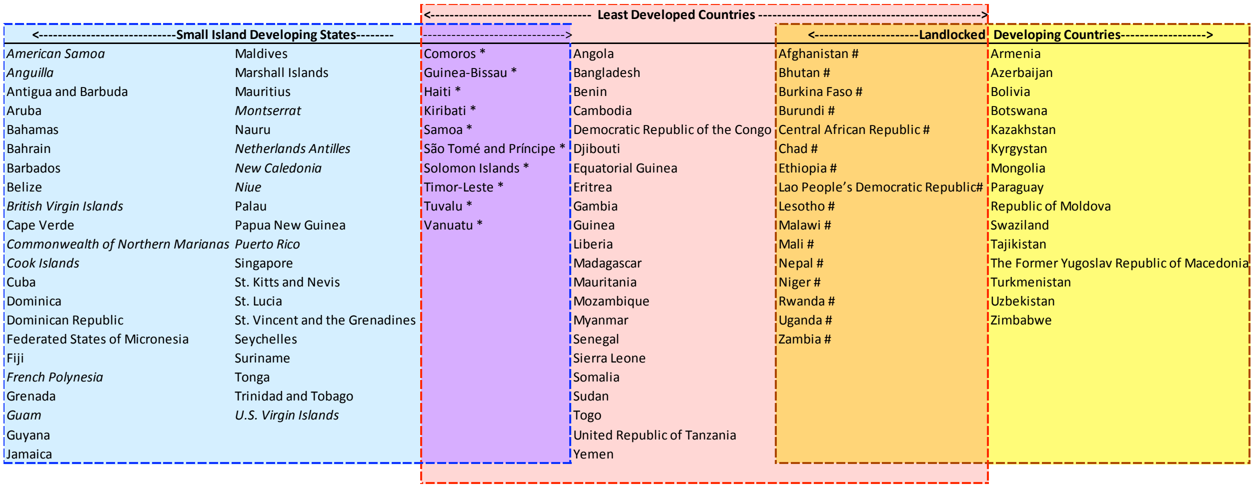


Figure 21-1: Mapping of the Annex I Parties onto members of the Organisation for Economic Co-operation and Development (OECD), European Union countries (including applicants) and Economies in Transition under the UNFCCC. Revised and updated from (Höhne et al., 2005).


<------------------------------ Least Developed Countries ------------------------------>

<----------------------------Small Island Developing States-------- ---------------------------->

<---------------------Landlocked Developing Countries----------------->

American Samoa
Anguilla
Antigua and Barbuda
Aruba
Bahamas
Bahrain
Barbados
Belize
British Virgin Islands
Cape Verde
Commonwealth of Northern Marianas
Cook Islands
Cuba
Dominica
Dominican Republic
Federated States of Micronesia
Fiji
French Polynesia
Grenada
Guam
Guyana
Jamaica

Maldives
Marshall Islands
Mauritius
Montserrat
Nauru
Netherlands Antilles
New Caledonia
Niue
Palau
Papua New Guinea
Puerto Rico
Singapore
St. Kitts and Nevis
St. Lucia
St. Vincent and the Grenadines
Seychelles
Suriname
Tonga
Trinidad and Tobago
U.S. Virgin Islands

Comoros *
Guinea-Bissau *
Haiti *
Kiribati *
Samoa *
São Tomé and Príncipe *
Solomon Islands *
Timor-Leste *
Tuvalu *
Vanuatu *

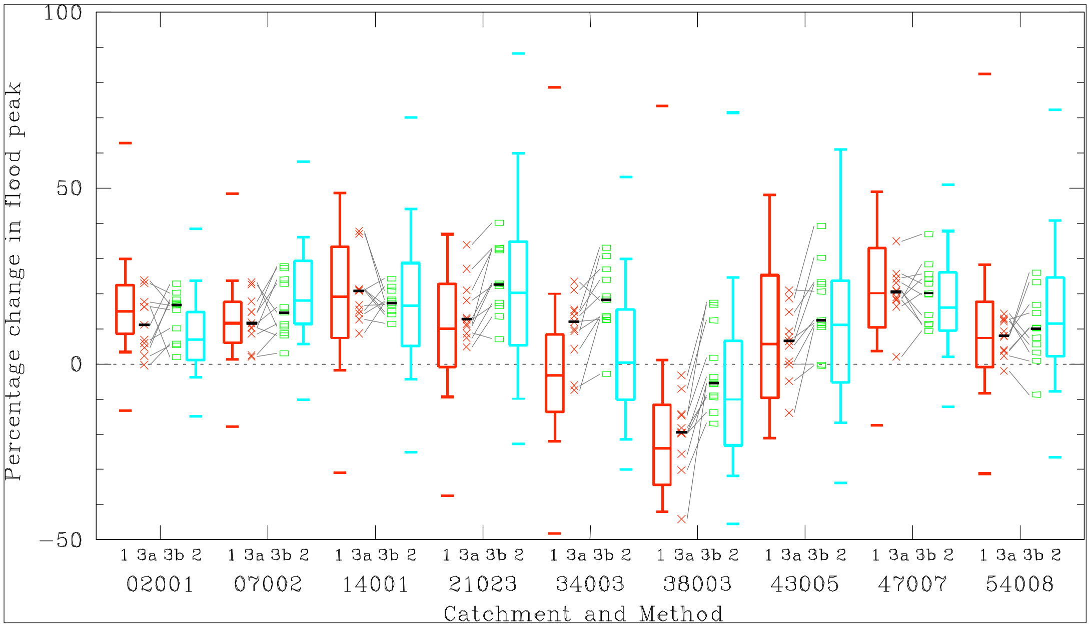
Angola
Bangladesh
Benin
Cambodia
Democratic Republic of the Congo
Djibouti
Equatorial Guinea
Eritrea
Gambia
Guinea
Liberia
Madagascar
Mauritania
Mozambique
Myanmar
Senegal
Sierra Leone
Somalia
Sudan
Togo
United Republic of Tanzania
Yemen

Afghanistan #
Bhutan #
Burkina Faso #
Burundi #
Central African Republic #
Chad #
Ethiopia #
Lao People's Democratic Republic#
Lesotho #
Malawi #
Mali #
Nepal #
Niger #
Rwanda #
Uganda #
Zambia #

Armenia
Azerbaijan
Bolivia
Botswana
Kazakhstan
Kyrgystan
Mongolia
Paraguay
Republic of Moldova
Swaziland
Tajikistan
The Former Yugoslav Republic of Macedonia
Turkmenistan
Uzbekistan
Zimbabwe

Figure 21-2: The Least Developed Countries (LDCs), Small Island Developing States (SIDS – marked with *) and Landlocked Developing Countries (LLDCs – marked with #). SIDS listed in italics are Non-UN Members / Associate Members of the Regional Commissions. Valid in June 2011 (OHRLLS, 2011).

a) 2-year return period



b) 20-year return period

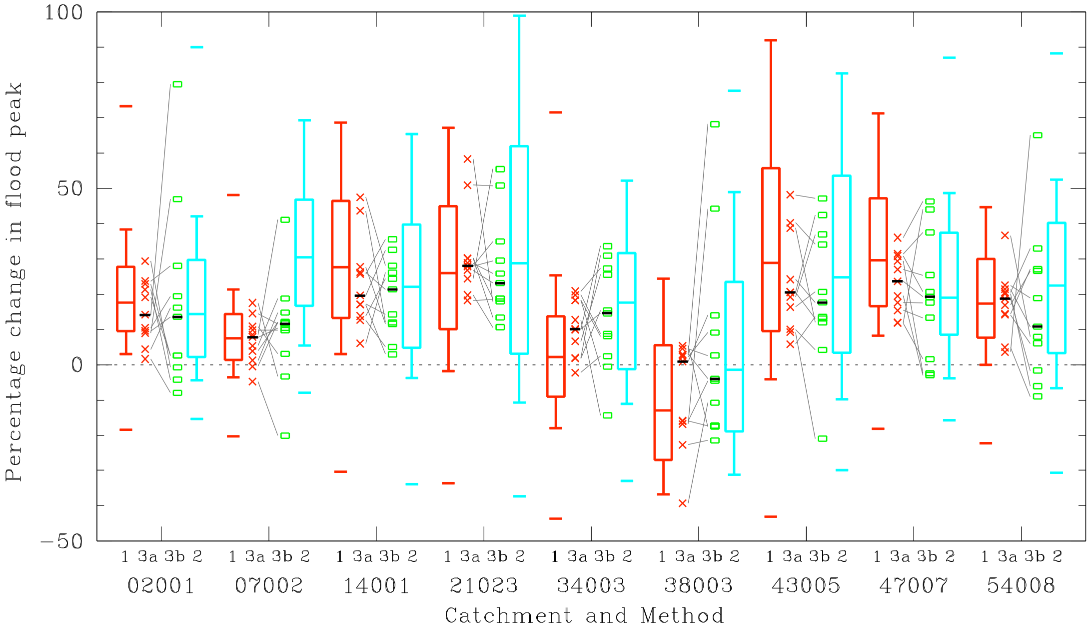


Figure 21-3: The range of percentage change in flood peaks for nine UK catchments at the a) 2-year and b) 20-year return period. Box-and-whisker plots are used to summarise results when using 10,000 UKCP09 Sampled Data (Murphy et al. 2009) change factors (red) and 100 sets of UKCP09 current and future 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.

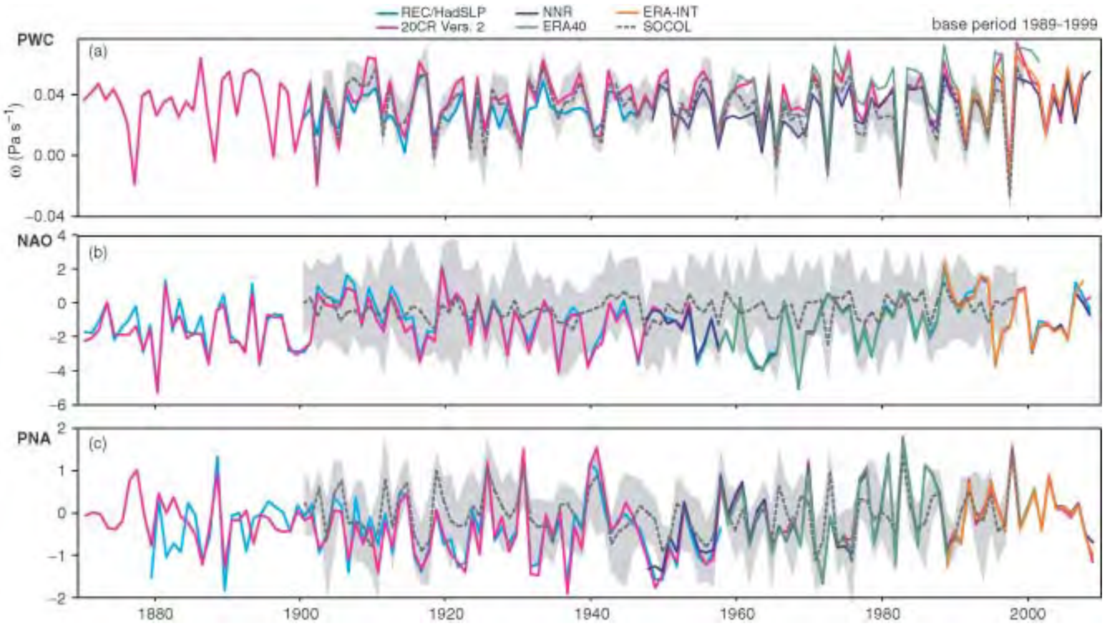


Figure 21-4: Time series of seasonally averaged climate indices representing (a) the tropical September to January Pacific Walker Circulation (PWC), (b) the December to March North Atlantic Oscillation (NAO), and (c) the December to March Pacific North America (PNA) pattern. Indices are calculated from 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).

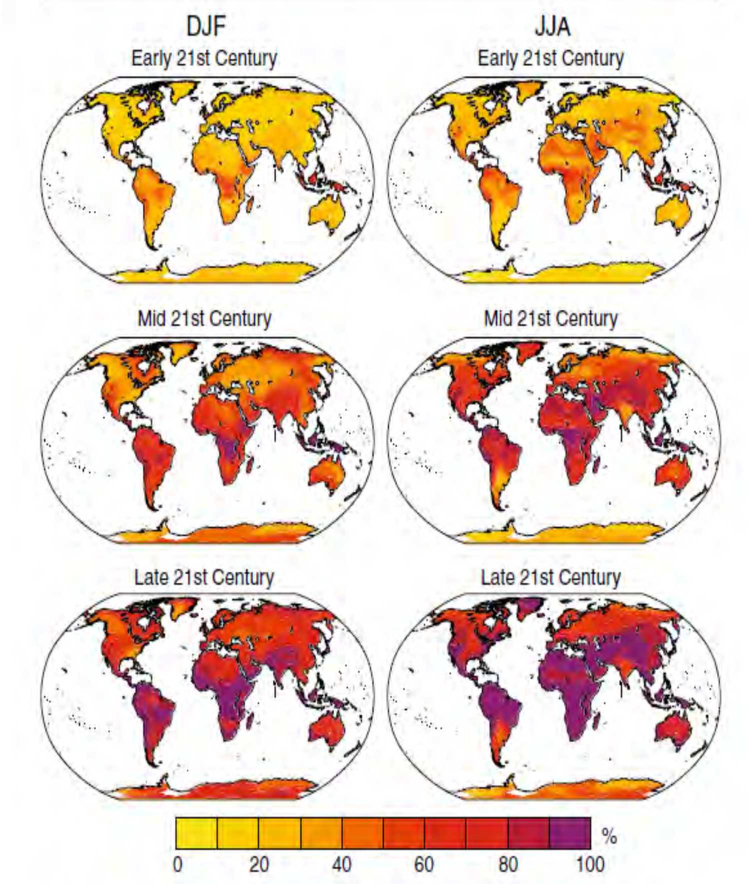


Figure 21-5: The percentage of seasons in the CMIP3 AIB ensemble for which the surface air temperature exceeds the warmest season of the 1980-199 period. The early 21st century period is 2010-2039, the mid 21st century period is 2040-2069, the late 21st century period is 2070-2099. (From Diffenbaugh et al. 2011).

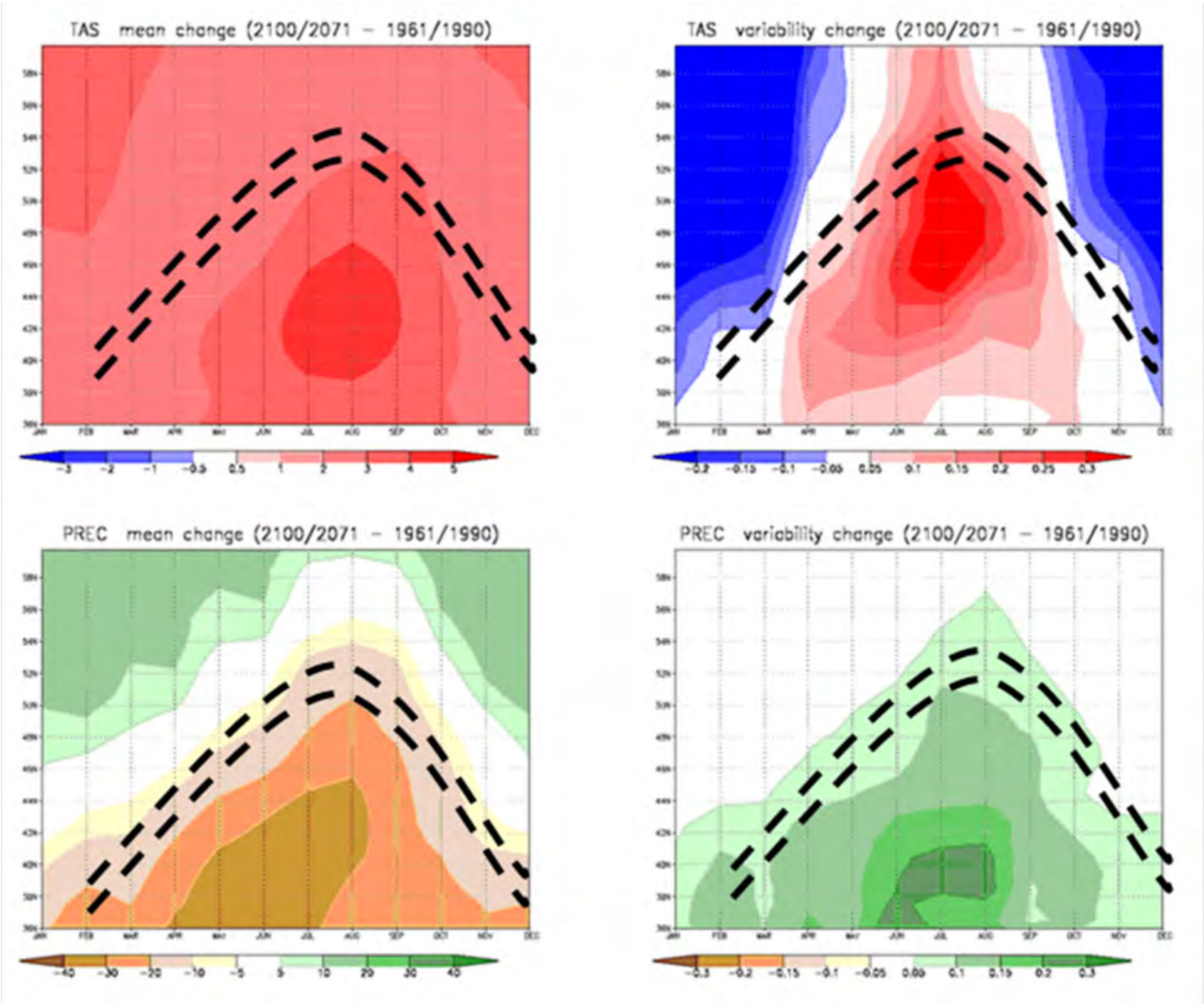


Figure 21-6: Monthly values of the zonally averaged changes in mean surface air temperature (top left panel), temperature interannual variability (as measured by the standard deviation, top right panel), mean precipitation (bottom left panel), precipitation interannual variability (as measured by the 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 Europen Climate Change Oscillation (ECO). From Giorgi and Coppola (2007).

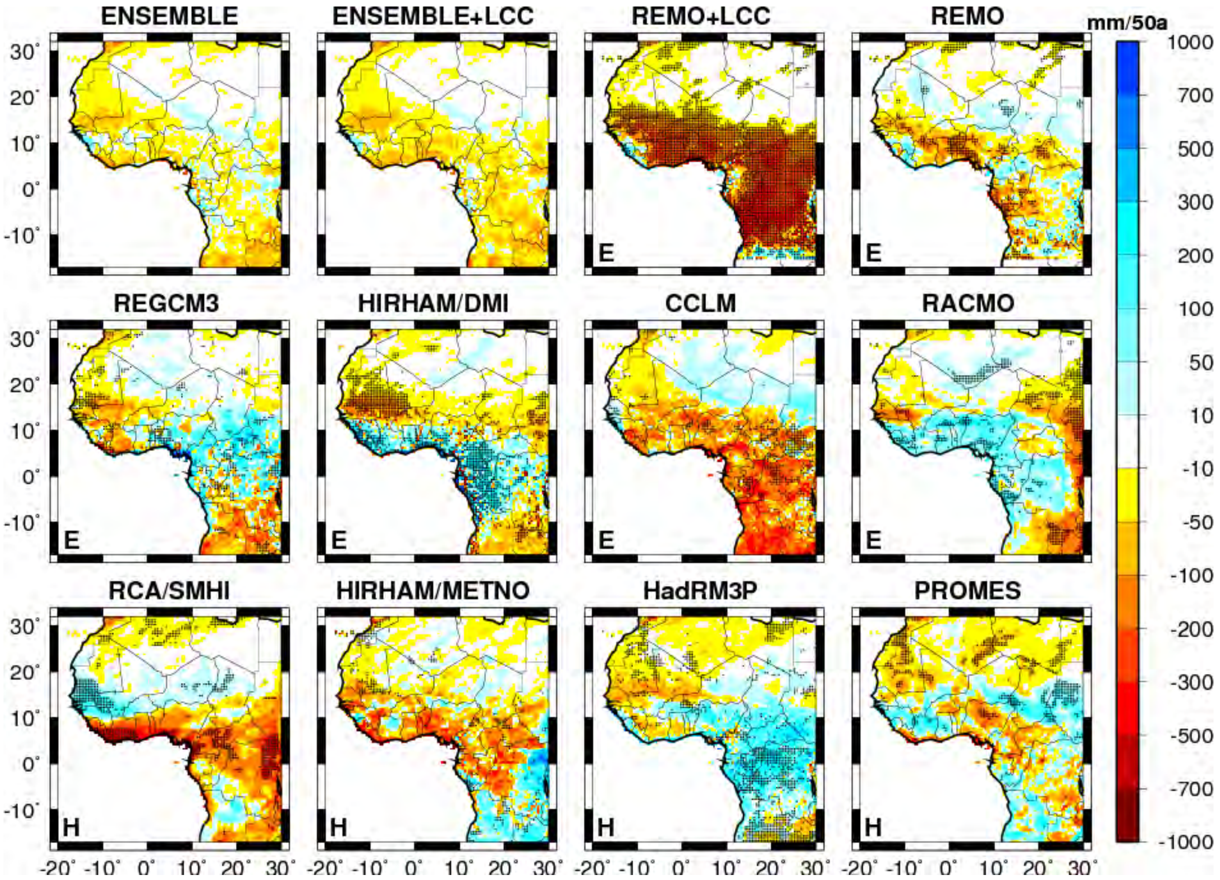


Figure 21-7: Linear changes of annual precipitation during the 2001-2050 period from 10 individual RCM experiments and the MME mean under the A1B emission scenario. The top middle panels also account for projected land cover changes (see text for further explanation). Note that the REMO trends in both 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).

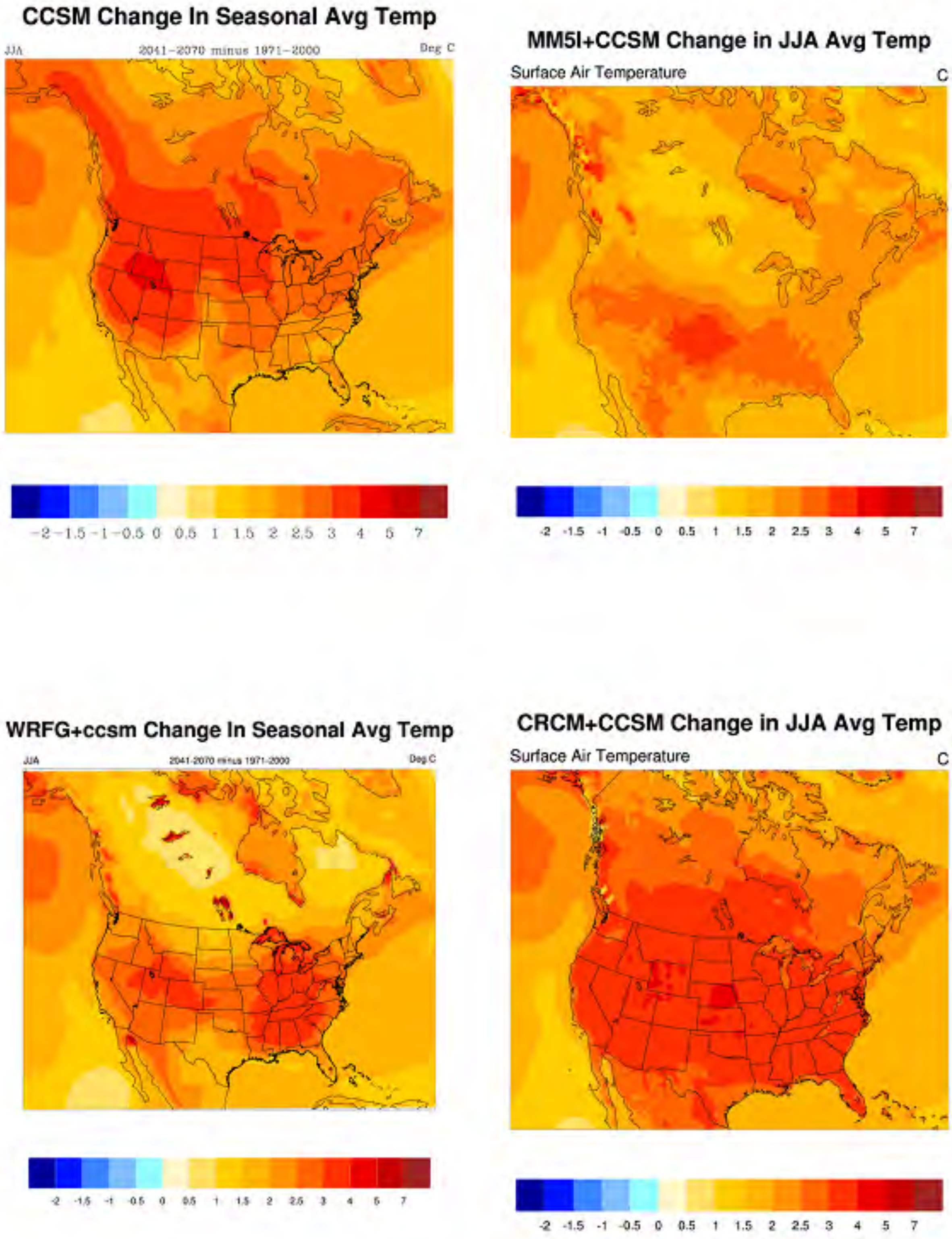


Figure 21-8: Change in summer (JJA) average temperature (2041-2070 minus 1971-2000) from (top left) the NCAR CCSM3, (top right) the MM5 regional climate model driven by the CCSM3; (bottom left) the WRF model, driven by CCSM3, and (bottom right) the Canadian CRCM, driven by CCSM3. Temperature is in °C. Data from the NARCCAP program. (From Mearns et al., 2009, 2011).

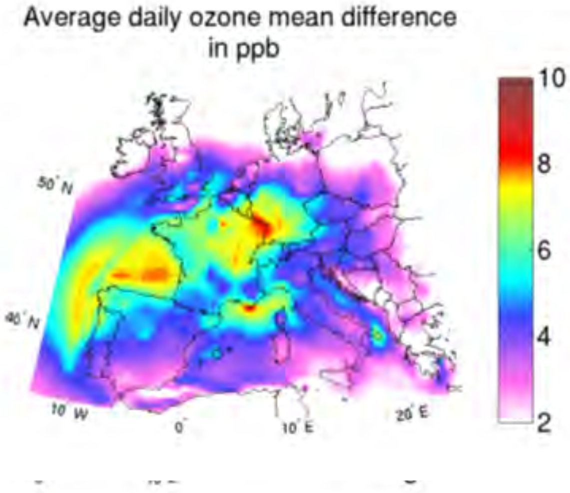


Figure 21-9: Difference in average summer daily ozone mean (left panel) and peak (right panel) concentration over Europe due to climate change, A2 scenario. (From Meleux et al. 2007).

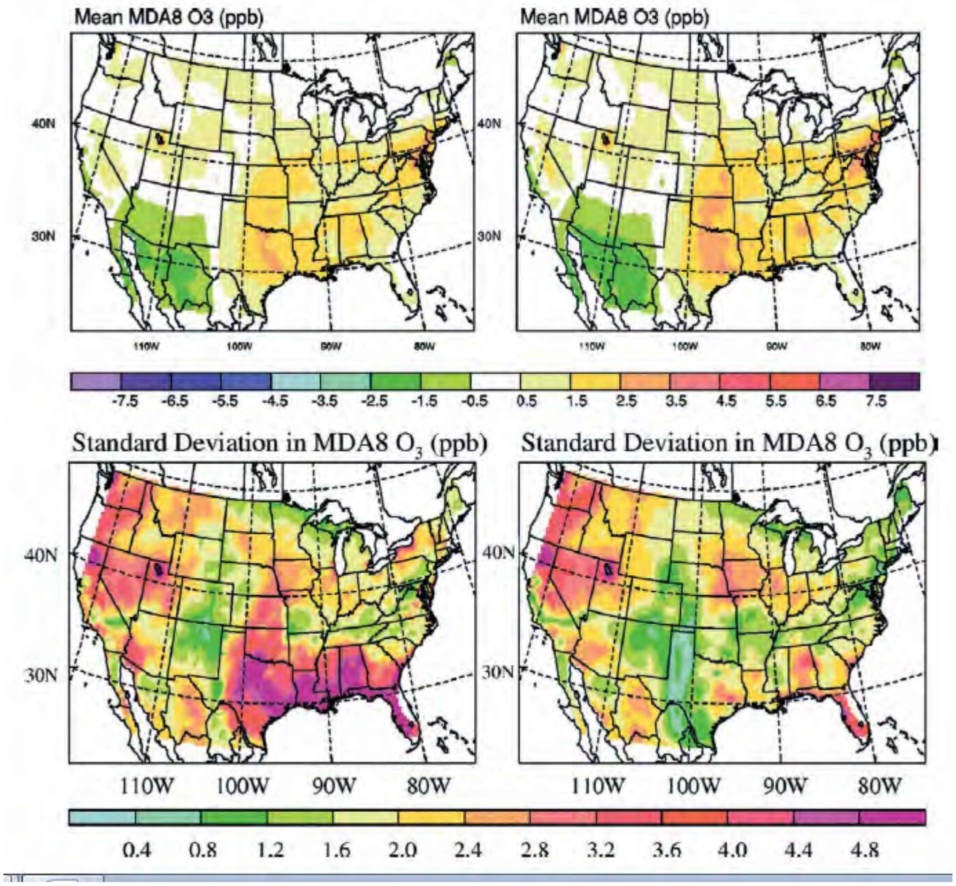


Figure 21-10: Mean (top panels) and standard deviation (bottom panels) in future-minus-present MDA8 summer ozone concentrations across (left-hand panels) all 7 experiments (5 regional and 2 global) and, for comparison purposes (right-hand panels) not including the WSU experiment (which simulated July only conditions). (From Weaver et al. 2009).

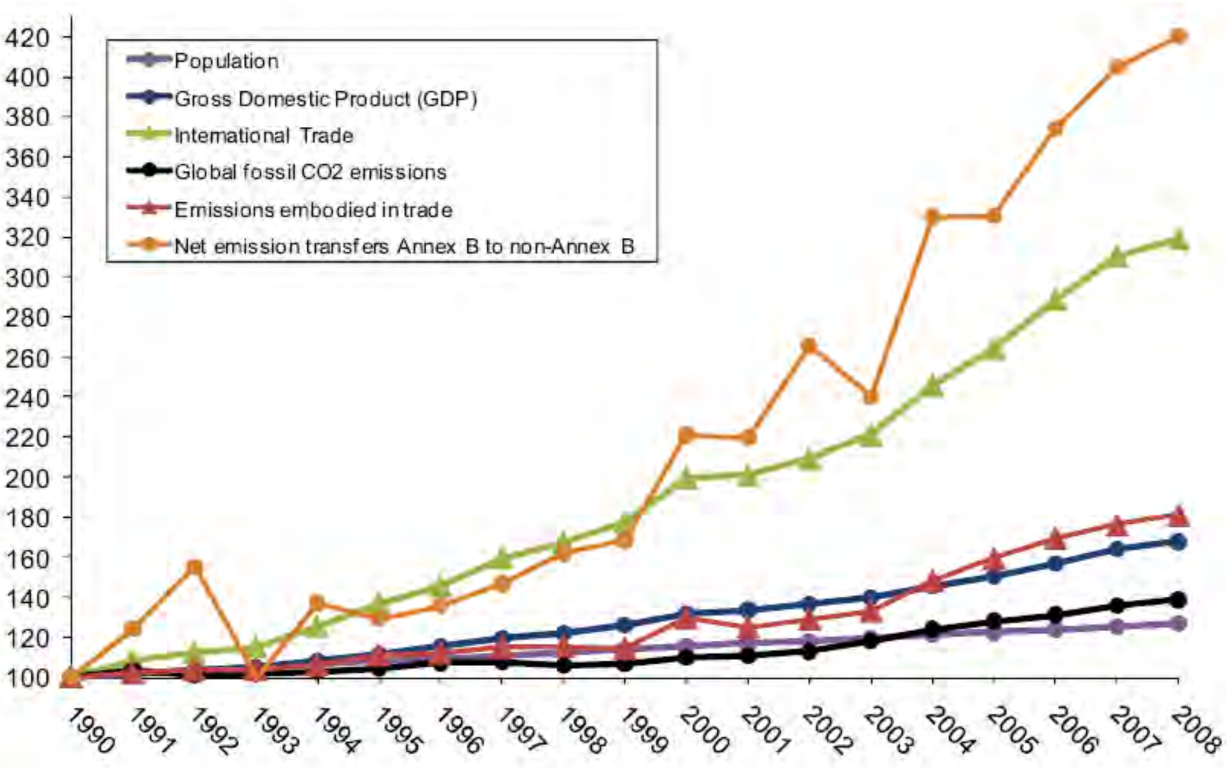


Figure 21-11: Growth rates from 1990-2008 of international trade, its embodied CO_2 emissions and net emissions transfers from Annex B and non-Annex B countries compared to other global macrovariables, all indexed to 1990 (Peters et al., 2011).

(Notes: Screen captured image - Carter)

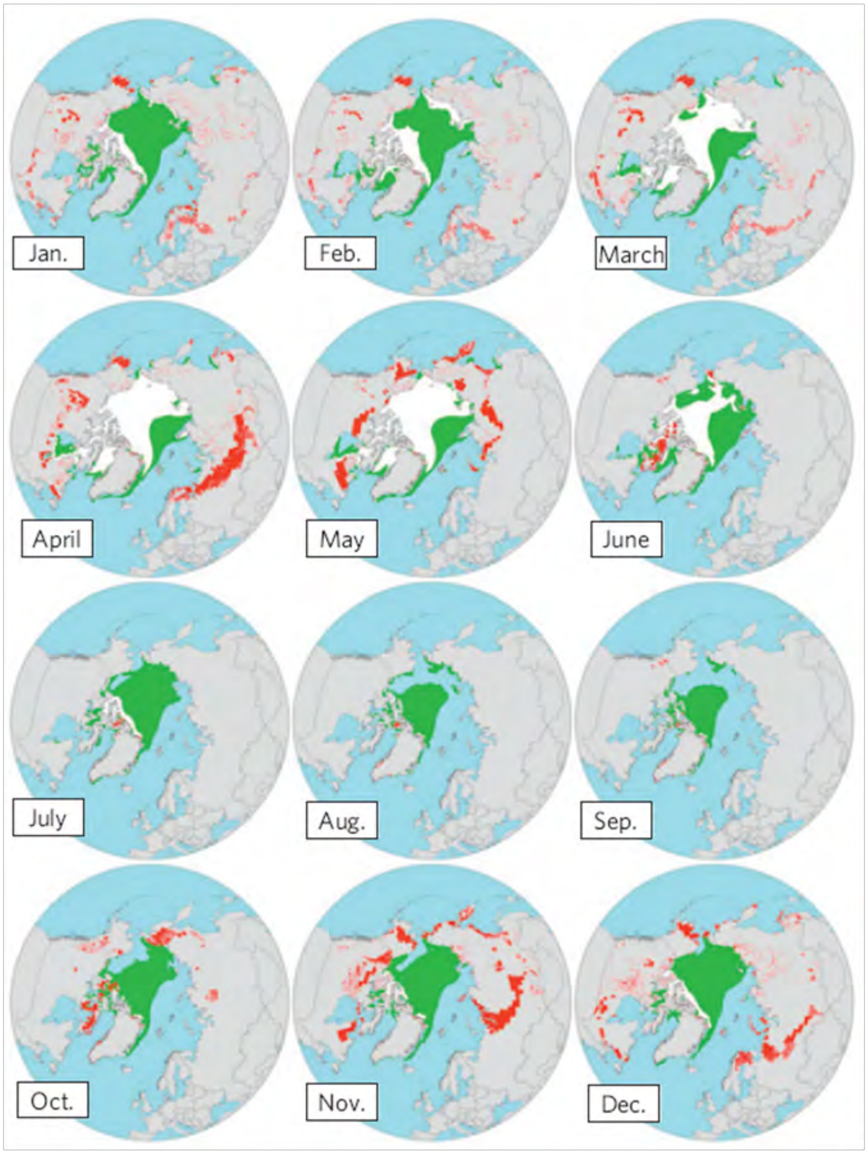


Figure 21-12: Projected change in accessibility of maritime and land-based transportation by mid-century (2045-2059 relative to 2000-2014) using the Arctic Transport Accessibility Model and CCSM3 climate and sea ice estimates assuming an SRES A1B scenario. Green areas denote new maritime access to Type 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).

(Notes: Screen captured image - Carter)

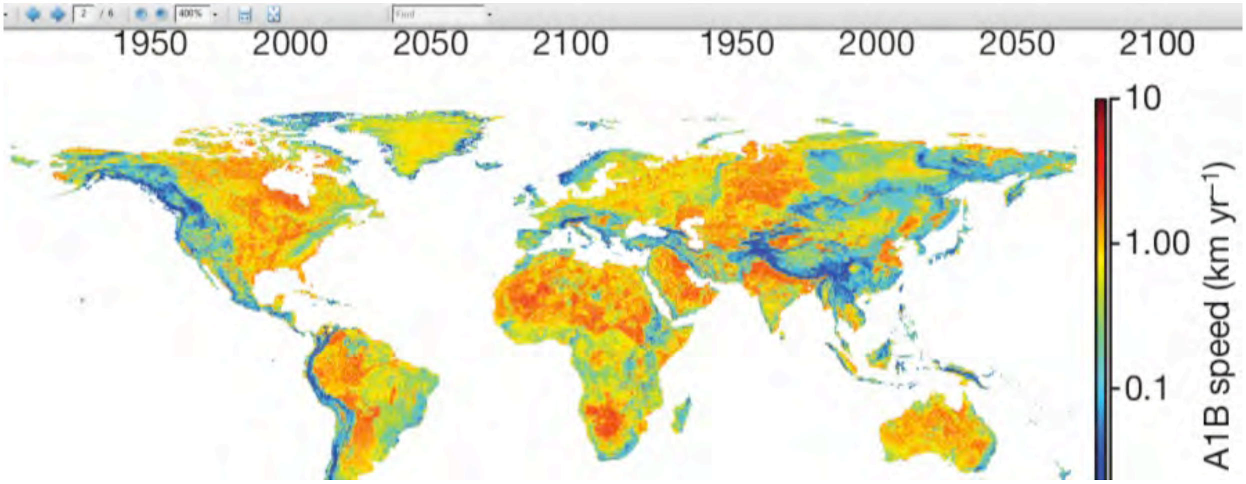


Figure 21-13: The velocity of climate change based on the average of 16 global climate models for an A1B emissions scenario and temporal gradients computed for 2050-2100. (Loarie et al., 2009).

(Notes: Screen captured image - Carter)

Supplementary Figures -- Not part of chapter. These figues are illustrative examples to spur further thinking about the methods of regionalisation adopted in previous assessments and lessons they might offer for regional treatment in the current report. We will, of course, drop them in the FOD, but they might help other chapters to think about how to present regional information based on earlier experience.

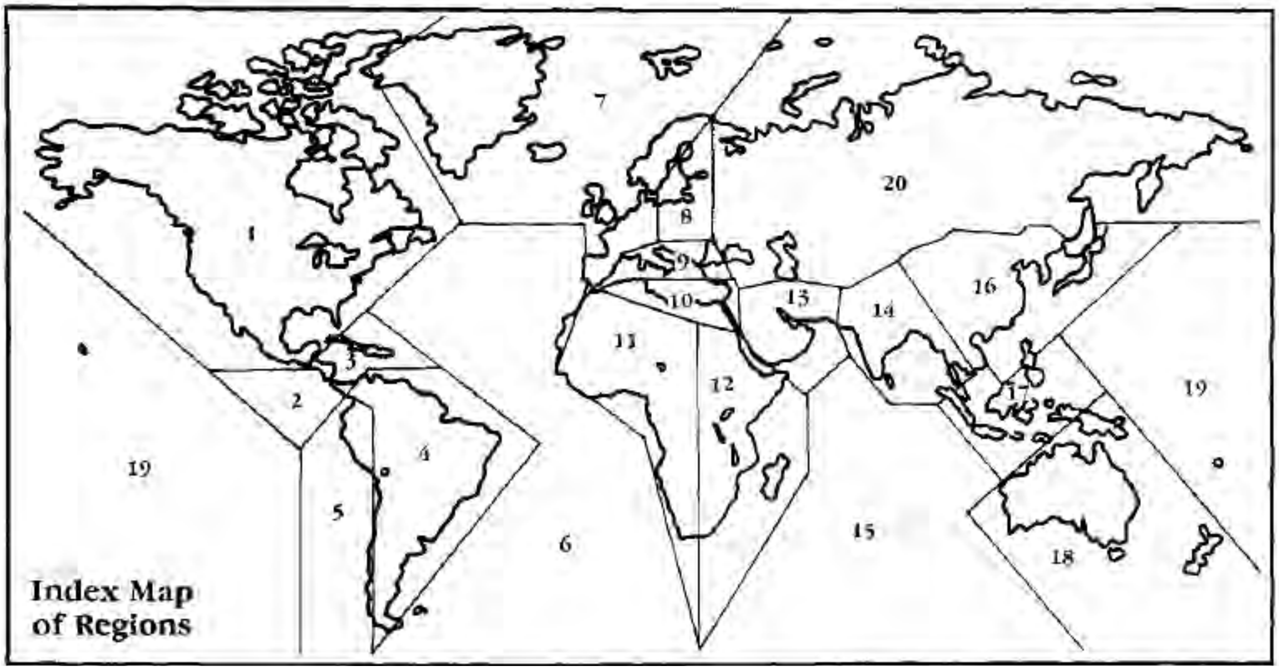


Figure B21.1.1. Regions defined for wetlands and for assessing coastal protection costs. 1. North America, 2. Central America, 3. Caribbean Islands, 4. South America Atlantic Ocean Coast, 5. South America Pacific Ocean Coast, 6. Atlantic Ocean Small Islands, 7. North and West Europe, 8. Baltic Sea Coast, 9. Northern Mediterranean, 10. Southern Mediterranean, 11. Africa Atlantic Ocean Coast, 12. Africa Indian Ocean Coast, 13. Gulf States, 14. Asia Indian Ocean Coast, 15. Indian Ocean Small Islands, 16. East Asia, 17. South-East Asia, 18. Pacific Ocean Large Islands, 19. Pacific Ocean Small Islands, 20. USSR. (Gilbert and Vellinga, 1990)

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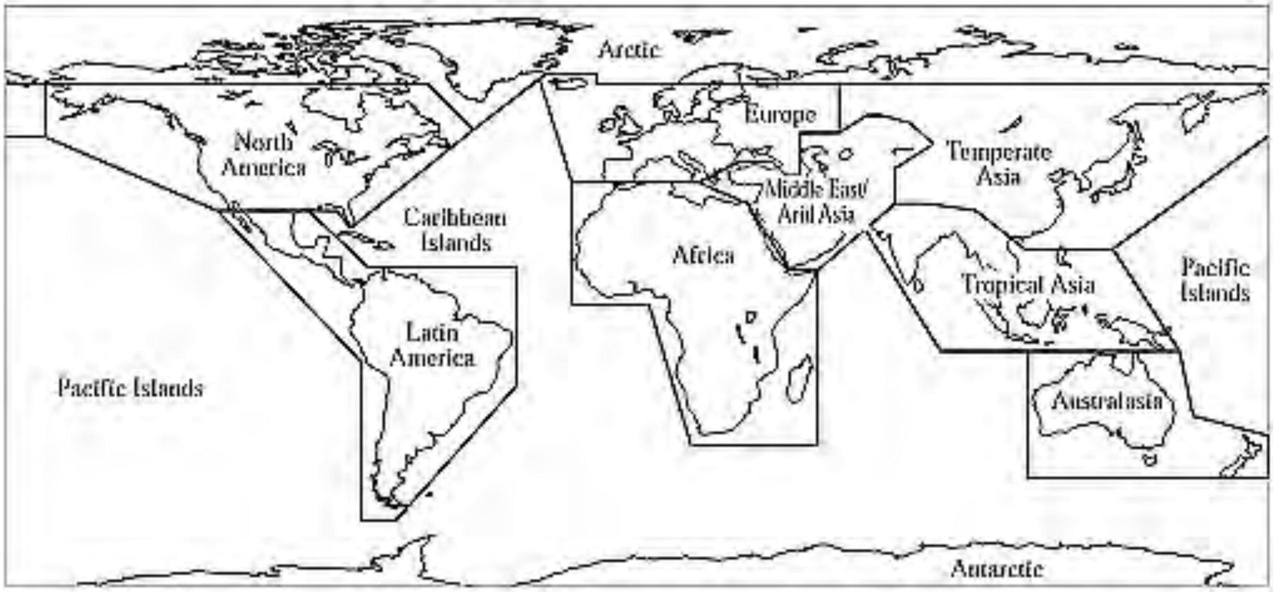

Figure B21.1.2. Ten regions defined for the Special Report on The Regional Impacts of Climate Change (Karl, 1998).

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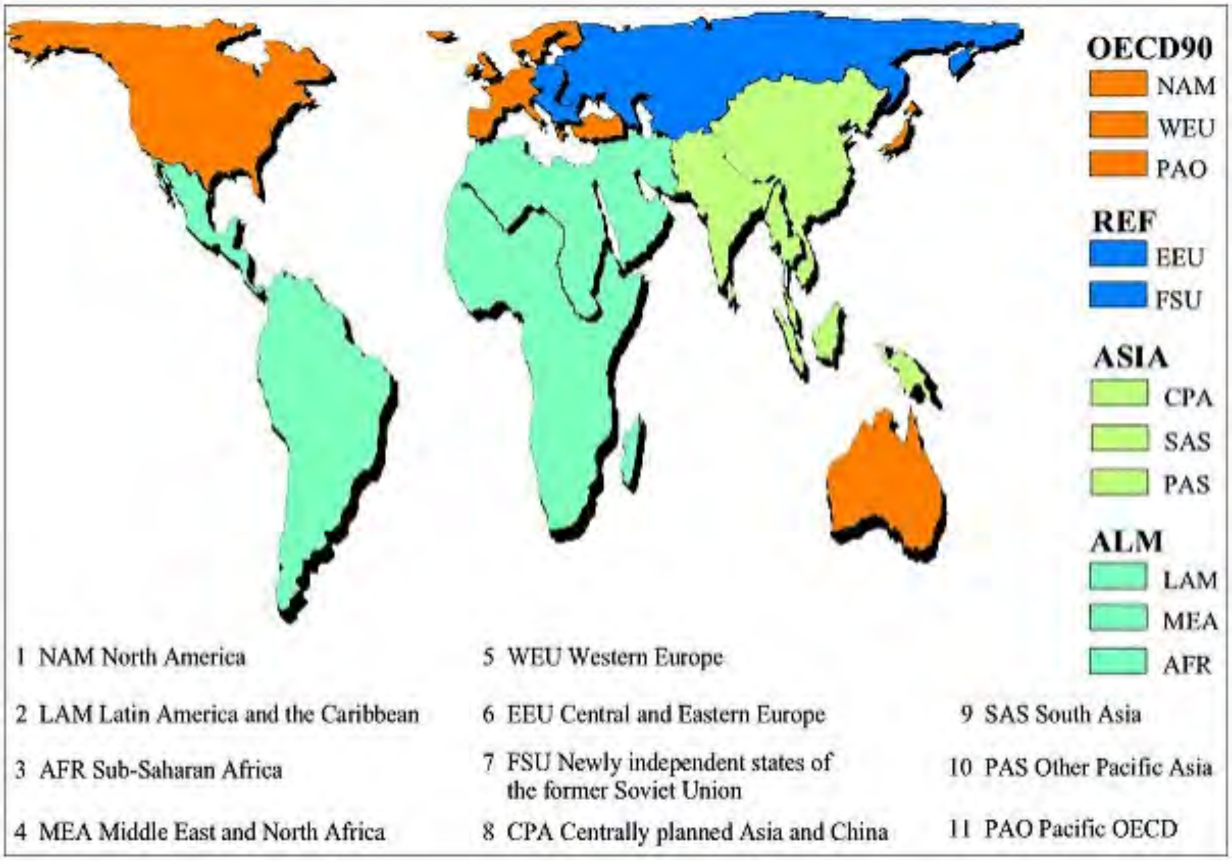
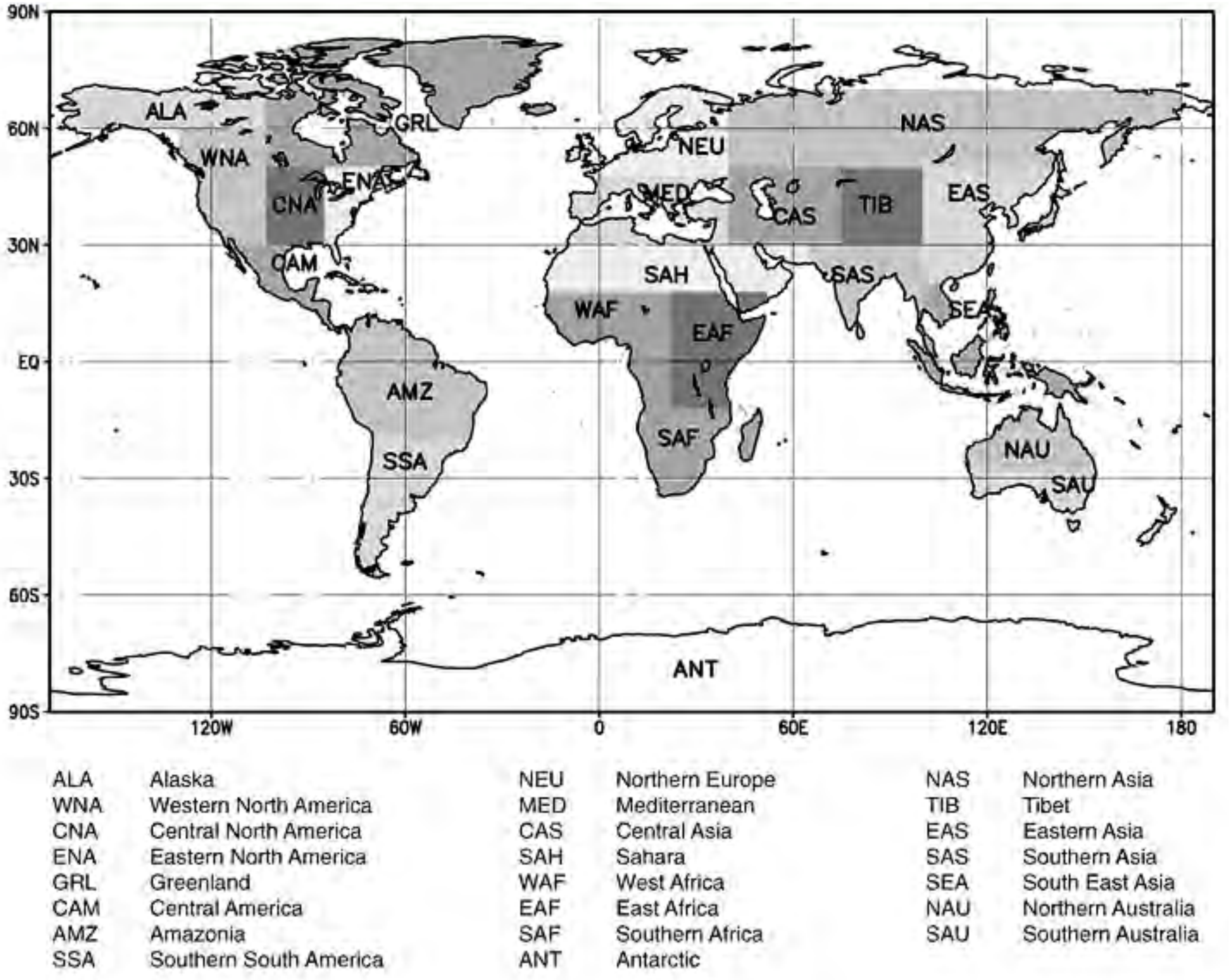


Figure B21.1.3. Four world regions and 11 sub-regions defined for the Special Report on Emissions Scenarios. The ALM and ASIA regions delimit the developing countries, approximately equivalent to the UNFCCC non-Annex 1 Parties (cf. Table 1). The industrialised countries comprise the OECD90 and REF regions, roughly corresponding to the Annex I Parties (IPCC, 2000b).

Screen captured image – Carter (New Zealand, Caribbean and other islands missing!)



ALA	Alaska	NEU	Northern Europe	NAS	Northern Asia
WNA	Western North America	MED	Mediterranean	TIB	Tibet
CNA	Central North America	CAS	Central Asia	EAS	Eastern Asia
ENA	Eastern North America	SAH	Sahara	SAS	Southern Asia
GRL	Greenland	WAF	West Africa	SEA	South East Asia
CAM	Central America	EAF	East Africa	NAU	Northern Australia
AMZ	Amazonia	SAF	Southern Africa	SAU	Southern Australia
SSA	Southern South America	ANT	Antarctic		

Figure B21.1.4. 23 Sub-continental regions defined for analysis of global model-based climate projections (Giorgi and Francesco, 2000).

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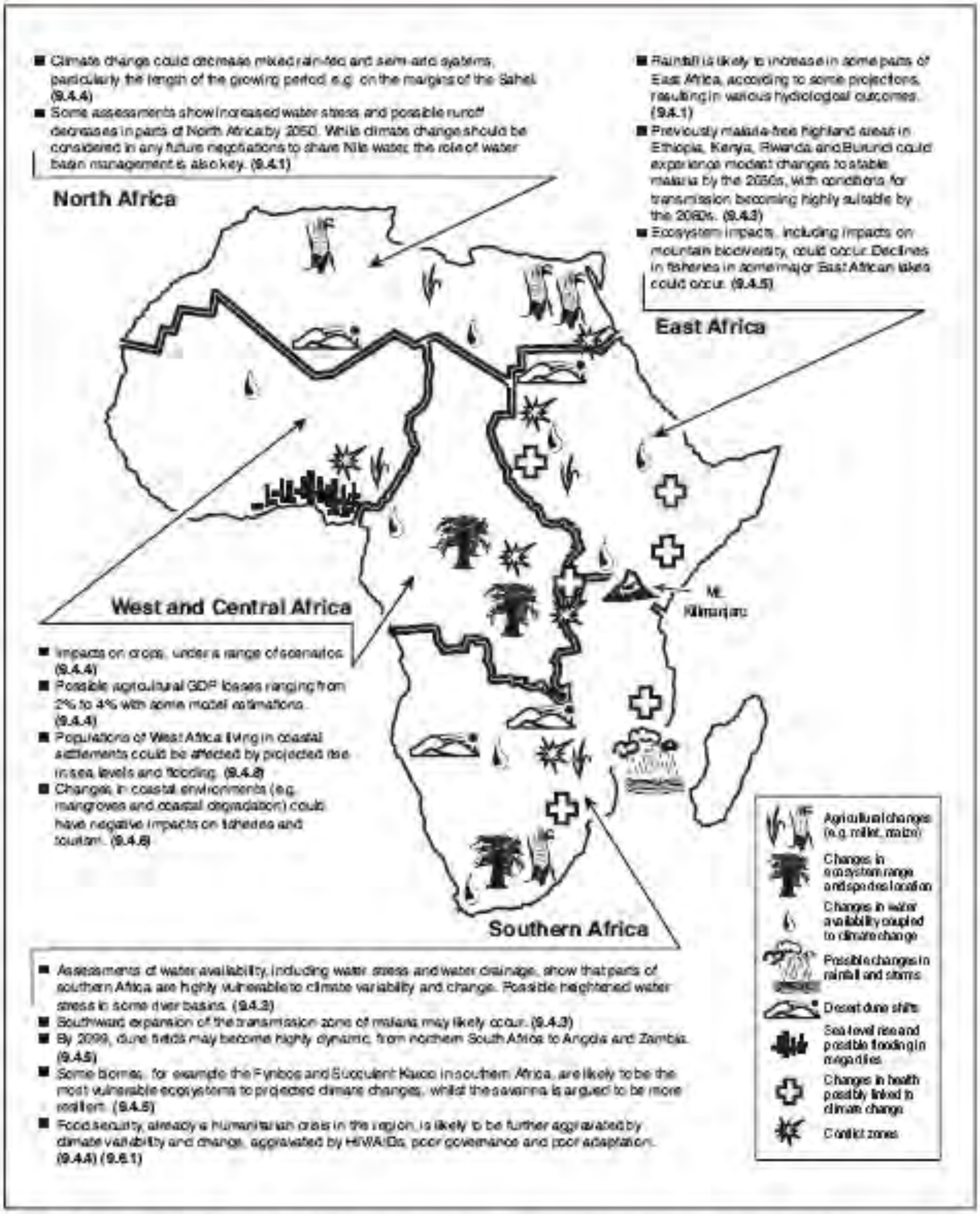

North Africa

- Climate change could decrease mixed rain-fed and semi-arid systems, particularly the length of the growing period e.g. on the margins of the Sahel. (9.4.4)
- Some assessments show increased water stress and possible runoff decreases in parts of North Africa by 2050. While climate change should be considered in any future negotiations to share Nile water, the role of water basin management is also key. (9.4.1)

East Africa

- Rainfall is likely to increase in some parts of East Africa, according to some projections, resulting in various hydrological outcomes. (9.4.1)
- Previously malaria-free highland areas in Ethiopia, Kenya, Rwanda and Burundi could experience modest changes to stable malaria by the 2050s, with conditions for transmission becoming highly suitable by the 2080s. (9.4.3)
- Ecosystem impacts, including impacts on mountain biodiversity, could occur. Declines in fisheries in some major East African lakes could occur. (9.4.5)

West and Central Africa

- Impacts on crops, under a range of scenarios. (9.4.4)
- Possible agricultural GDP losses ranging from 2% to 4% with some model estimations. (9.4.4)
- Populations of West Africa living in coastal settlements could be affected by projected rise in sea levels and flooding. (9.4.6)
- Changes in coastal environments (e.g. mangroves and coastal degradation) could have negative impacts on fisheries and tourism. (9.4.6)

Southern Africa

- Assessments of water availability, including water stress and water drainage, show that parts of southern Africa are highly vulnerable to climate variability and change. Possible heightened water stress in some river basins. (9.4.3)
- Southward expansion of the transmission zone of malaria may likely occur. (9.4.3)
- By 2099, dune fields may become highly dynamic, from northern South Africa to Angola and Zambia. (9.4.5)
- Some biomes, for example the Fynbos and Succulent Karoo in southern Africa, are likely to be the most vulnerable ecosystems to projected climate changes, whilst the savanna is argued to be more resilient. (9.4.5)
- Food security, already a humanitarian crisis in the region, is likely to be further aggravated by climate variability and change, aggravated by HIV/AIDs, poor governance and poor adaptation. (9.4.4) (9.6.1)

Figure B21.1.5. Examples of current and potential future vulnerabilities to climate change in different regions of Africa (Boko *et al*., 2007).

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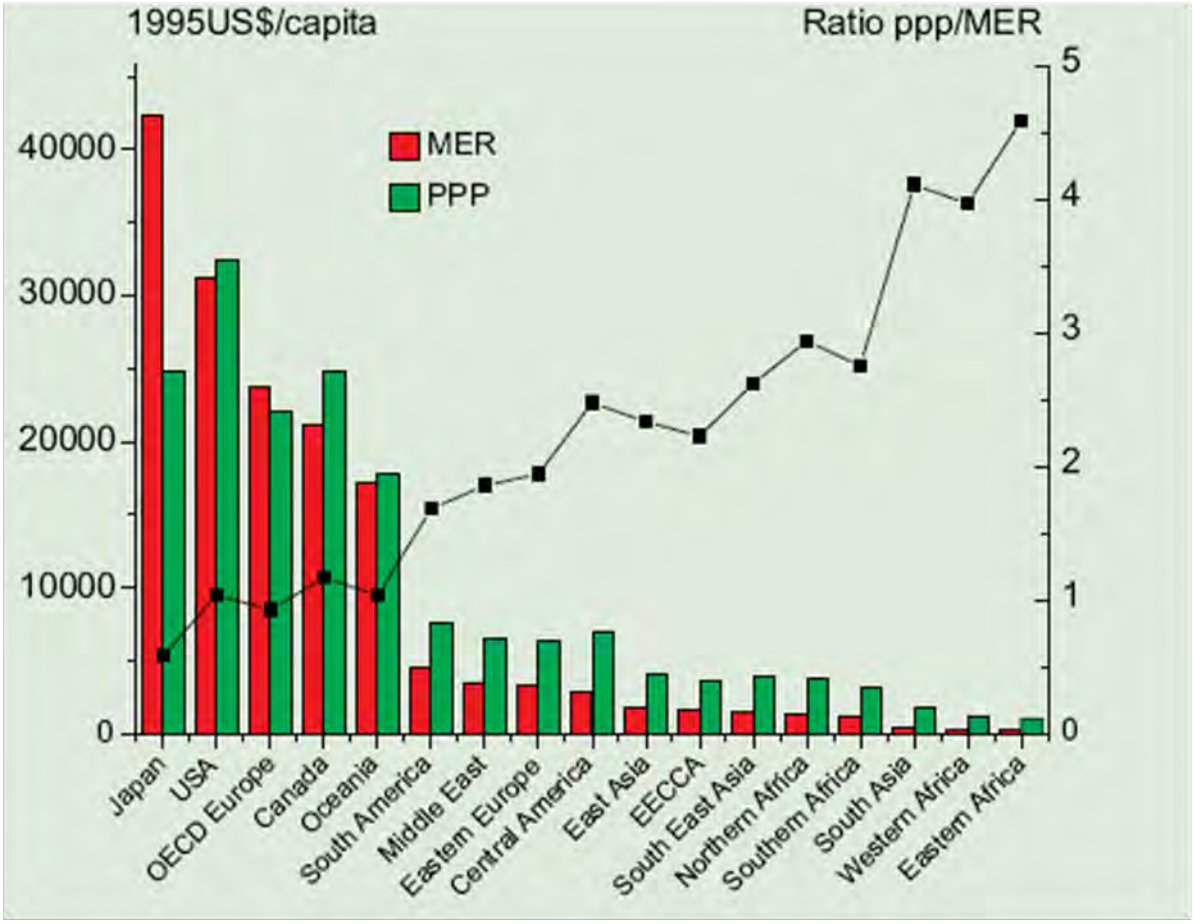

Figure B21.1.6. Regional GDP per capita expressed in Market Exchange Rates and Purchasing Power Potential based on World Bank data aggregated to 17 world regions (Fisher *et al.*, 2007).

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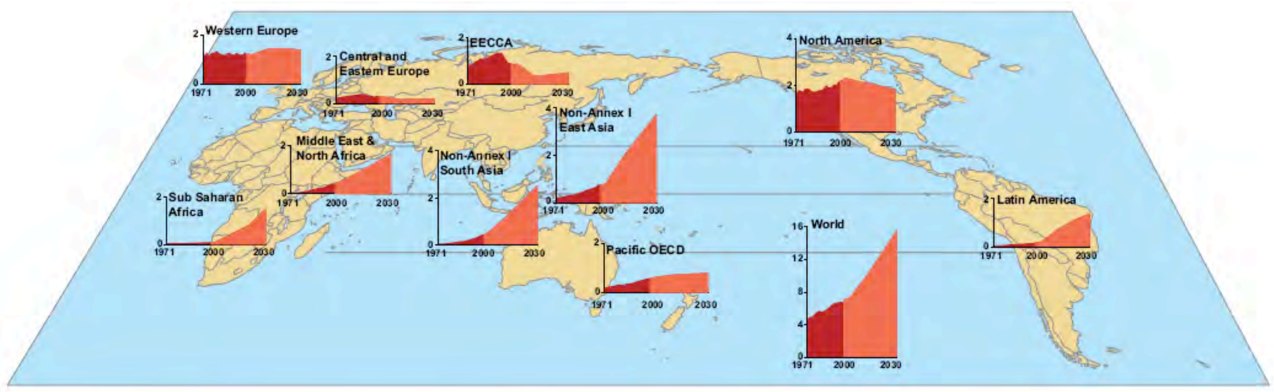

Figure B21.1.7. Trends in CO_2 emissions from electricity use 1971-2000 and projections for 2001-2030 based on the SRES A1B scenario (Levine *et al*., 2007).

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